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The Distribution of *Neomysis americana* in the Estuary of the Delaware River¹

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ABSTRACT

Observations on the planktonic shrimp, *Neomysis americana* (Smith), in the Delaware River estuary were carried out over a period of two years. It was found that *Neomysis* was far more abundant in the deep water of the estuary than in the near-surface or shallow water. Moreover, it was more abundant within the estuary than in the coastal waters at the mouth of Delaware Bay. Measurements of the length of the animal showed increase in size from the ocean toward the river end of the estuary. These features are interpreted in light of the probable circulation of the estuary to show that the animals became older during their "up-estuary" drift in deep water. Furthermore, they tended to accumulate within the estuary due to their avoidance of the out-flowing surface waters. A principal source for *Neomysis* in the coastal waters outside the Bay is thus suggested. During spring and summer, however, reproduction within the Bay contributed to the stock of animals there. The up-estuary extent of *Neomysis* was related to the 4‰ isohaline, and the partial exclusion from surface waters was attributed to their avoidance of excessive light.

INTRODUCTION

The dispersal of a planktonic organism by currents has long been of some, though usually minor, interest. Only a few studies have made this feature a principal theme. For instance, Redfield (1939) described the fate of a population of the planktonic snail, *Limacina retroversa*, after drifting into the Gulf of Maine. This drift was the result of a discrete influx of water from the continental shelf into the Gulf of Maine. The decrease of a constituent of the bacterial flora introduced from the Raritan River as it drifted along the estuary toward the sea was analyzed quantitatively as an effect of dilution, mortality, and predation by Ketchum *et al.* (1952). By the same method Barlow (1955) was able to show that in the landward portion of a small estuary a

population of the copepod, *Acartia tonsa*, grew actively. After drifting into the seaward portion it died rapidly. Here the rate of the biological change was evaluated from the rate of water exchange. Thus, it would appear that by using water movement as a tool the change of the characteristics of a population in space can be reasonably interpreted. In this way a true area of production can be differentiated from a marginal area to which the population is carried but where it cannot reproduce.

The present account shows that the planktonic mysid shrimp, *Neomysis americana* (Smith), was abundant within the estuary of the Delaware River throughout two years of study. By taking into consideration the probable circulation of the estuary and the size distribution of the shrimp along the axis of the estuary, it is concluded that this abundance is in part the result of reproduction under estuarine conditions and in part the result of entrainment

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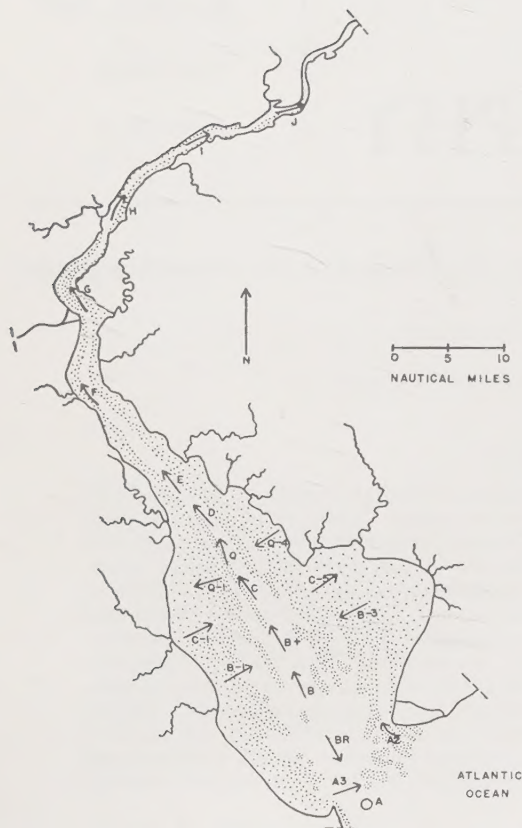


FIG. 1. The estuary of the Delaware River (excluding the portion from Philadelphia to Trenton). The 18-foot depth contour separates shallower stippled areas from deeper unstippled areas. The letters and broad lines show the approximate positions of stations. The arrowheads indicate the usual direction in which the sampling runs were made.

into the estuary of populations living in the ocean waters beyond.

The following study describing the distribution of a single planktonic species in the estuary of the Delaware River has been carried out as a part of a study of the zooplankton of the Bay and tidal portion of the River under the direction of Dr. L. E. Cronin. The author is deeply indebted for encouragement and guidance from Dr. Cronin. For the preparation of the graphs of Figure 2 by Mrs. A. J. Mansueti and for use of salinity data gathered by Mr. Warren Schneller he owes the best thanks. This work was carried out under Contract Nonr-509(00) between the Office of Naval Research and the University of Delaware.

CHARACTERISTICS OF THE ESTUARY OF THE DELAWARE RIVER

The estuary of the Delaware River (Fig. 1) is situated on the Atlantic Coast of the United States. It is composed of a narrow, landward portion and a wide, seaward portion, the Delaware Bay. In broad terms, the margins of the Bay and tidal portion of the River are quite shoal, being less than 18 feet deep. Water deeper than 18 feet is more usual toward the center of the estuary. Figure 1 shows how the 18-foot contour outlines a series of sloughs, which radiate from the entrance into the Bay. One of these, the channel, continues into the narrow, river-like portion of the estuary and has a dredged depth of 40 feet, except at the entrance where the depth is 60–80 feet. Stations are shown in the figure and are lettered alphabetically up-estuary, that is, as one proceeds landward from the ocean.

METHODS

Samples were taken with a Clarke-Bumpus sampler and #2 silk net with an aperture of 5 inches. The net was towed for an hour at a speed of approximately 3 miles per hour and usually strained between 20 and 50 cubic meters of water. Tows in the channel were made in the direction of the axis of the estuary, while those in the margins were across the axis of the estuary. At channel stations nets were towed simultaneously at the surface, 20 feet, 40 feet, and, at the entrance only, at 60 feet. In the marginal areas surface tows were always made, while tows at 4–5 feet were made about 50 % of the time. On August 12–13, 1952, tows were made at 4-hour intervals over a 26-hour period at Station A. At virtually all other times tows were made during daylight only.

The estuary was sampled during each season for two years. The dates of the various cruises are as follows:

Cruise	Date
I	10 Oct.–10 Nov. 1951
II	30 Nov.–3 Dec. 1951
III	1 Feb.–8 Feb. 1952
IV	22 May–29 May 1952
V	18 Aug.–22 Aug. 1952
VI	10 Nov.–17 Nov. 1952
VII	5 Feb.–12 Feb. 1953
VIII	30 May–6 June 1953
IX	20 Aug.–25 Aug. 1953

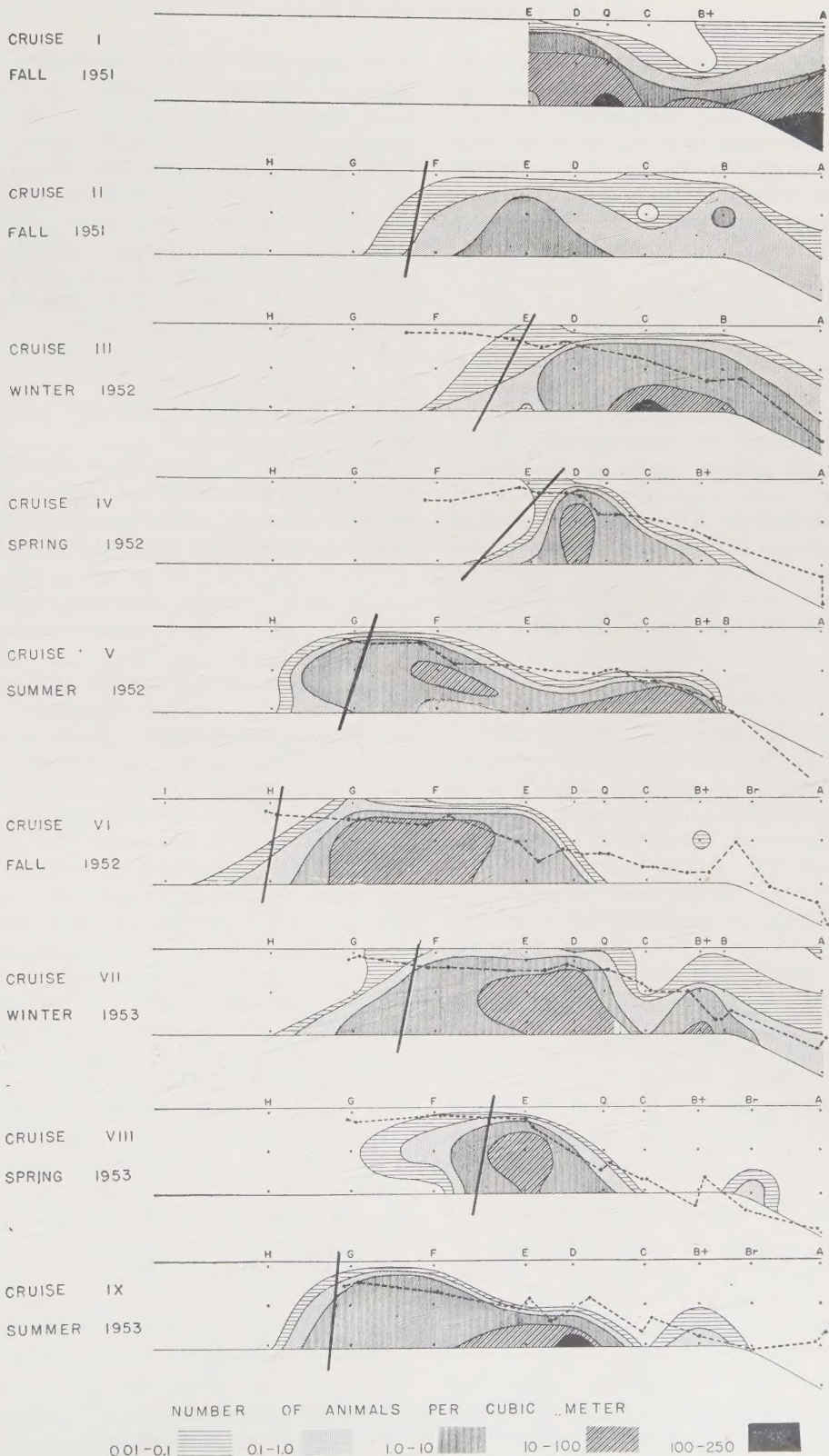


FIG. 2. The vertical distribution of *Neomysis americana* along the axis of the estuary. The dashed line is the depth of the critical light intensity. The nearly vertical straight line is the 4‰ isohaline.

Salinity determinations were made by the Knudsen method. Transparency was measured by Secchi disc. Measurements of the animals were made from the tip of the blade of the antenna to the tip of the uropod. Thirty-three animals were measured from each sample, except where the sample contained fewer than this number.

RESULTS

The distribution of Neomysis americana

Figure 2 shows the vertical distribution of *Neomysis americana* in the channel stations along the axis of the estuary. Usually this mysid was found only very sparsely, $<0.10/\text{m}^3$, at the surface, while at the bottom relatively large concentrations, $>10/\text{m}^3$, were often found. This feature occurred on all the cruises and at most of the stations

where the mysid was at all abundant. The variation between the surface and bottom count was often 100-fold or more. In only a minor number of cases was the variation as slight as ten-fold, and in only one (Cruise III, Station E) was the surface concentration the same as the bottom concentration.

The large concentrations of mysids were closer to the surface at the up-estuary stations, D-F, than at the down-estuary stations, A-C. Thus, at Stations D to F high concentrations occurred at the bottom and at 20 feet; at Stations A to C, high concentrations occurred predominantly at the bottom.

The distribution of mysids in the shallow water toward the margins of the Bay is presented in Figure 3. For the most part only negligible amounts of mysids occurred here.

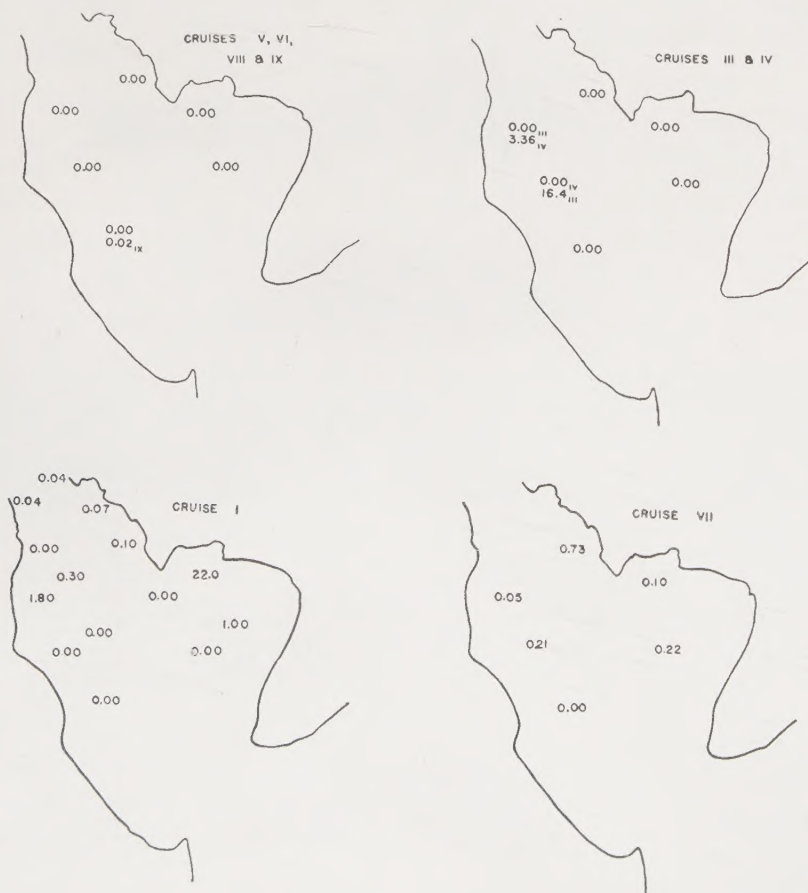


FIG. 3. The surface distribution of *Neomysis americana* in the marginal areas of Delaware Bay. Values are numbers of animals per cubic meter. Roman numerals are cruise numbers.

On Cruises V, VI, and VIII none were caught. On Cruise IX none were detected at five out of six stations, while a very small concentration occurred at a single station. On Cruise III none were caught at five out of six stations, but a large concentration, $16/\text{m}^3$, was present at one station. Cruise IV showed about the same situation as Cruise III. Cruises VII and I showed mysids at a number of marginal stations, usually in very small concentrations but occasionally in large concentrations.

Along the length of the estuary mysids were often present in large concentrations from the entrance well into the narrowed portion of the estuary (Stations E to H), as shown in Figure 2. Between Stations E and H there was always an abrupt decrease, upstream from which mysids were present only in traces or not at all. Roughly, they appeared in greater concentrations up-estuary than down-estuary, Cruise I being the only distinct exception. It is apparent from Figure 2 that the concentrations of *Neomysis* at the entrance varied a great deal from cruise to cruise, while up-estuary the variations were far less. As a result of this feature, on Cruises IV, V, VI, and IX the populations appeared to be located wholly within the estuary rather than to be continuous from the ocean far up the estuary.

Figure 2 shows that during spring and summer (Cruises IV, V, VIII, and IX) *Neomysis americana* was undetectable at the mouth of Delaware Bay. Fall and winter cruises, on the other hand, were marked usually by the presence of mysids at the entrance of the Bay, once in large concentration. Within the estuary in a section bounded roughly by Stations C and E, there was little variation of a seasonal character. The point up-stream from Station E where *Neomysis americana* abruptly decreased varied with the seasons. The point was farther up-stream in the summer and fall and farther down-stream in winter and spring, particularly spring.

It is apparent that there are other variations which are not trends along the length of the estuary or through the year. The very large concentration at the mouth of the Bay on Cruise I ($215/\text{m}^3$ at 50 feet) con-

TABLE 1. The vertical distribution of *Neomysis* during day and night at Station A, expressed as number of animals per cubic meter

Depth ft	Time			
	14:51- 15:51	17:54- 18:54	00:04-1:04	02:56-03:56
0	0	0	0.56	0.22
20	0	0	4.84	1.15
40	0	0	13.71	19.35
60	0	0	38.80	43.40
	07:00- 08:00	09:15- 10:15	12:18-13:18	15:49-16:49
	0	0	0	0
20	0	0	0.07	0
40	0	0	0	0
60	0	0	0	0

trasted sharply with values there at other times, ranging from $0.34/\text{m}^3$ to none at all. On Cruise V at Station B⁺ a count of $35/\text{m}^3$ was flanked closely by a zero concentration (or less than about $0.05/\text{m}^3$) at the next seaward station.

Diurnal variation of *Neomysis americana*

Table 1 shows the vertical distribution at approximately 4-hour intervals during the day and night at Station A at the entrance of the Bay. During the daylight hours almost no specimens of *Neomysis* were caught, even in the net towed at 60 feet. But during the night animals were caught at all depths. Even then, the larger concentrations were at deeper levels.

It is quite possible that during the day mysids congregated below 60 feet, since within half a mile of Station A depths greater than 80 feet were prevalent. The possibility that mysids came from the estuary on an outgoing tide is eliminated, since incoming tide occurred when the night catches were made.

Length measurements of *Neomysis americana*

Length measurements of *Neomysis* from samples collected along the bottom and at 20 feet are presented in Figures 4, 5, and 6. In the six cruises studied in this way there was always a distinct tendency for large individuals, represented by the extreme right portion of the histograms, to become still larger in an up-estuary direction. His-

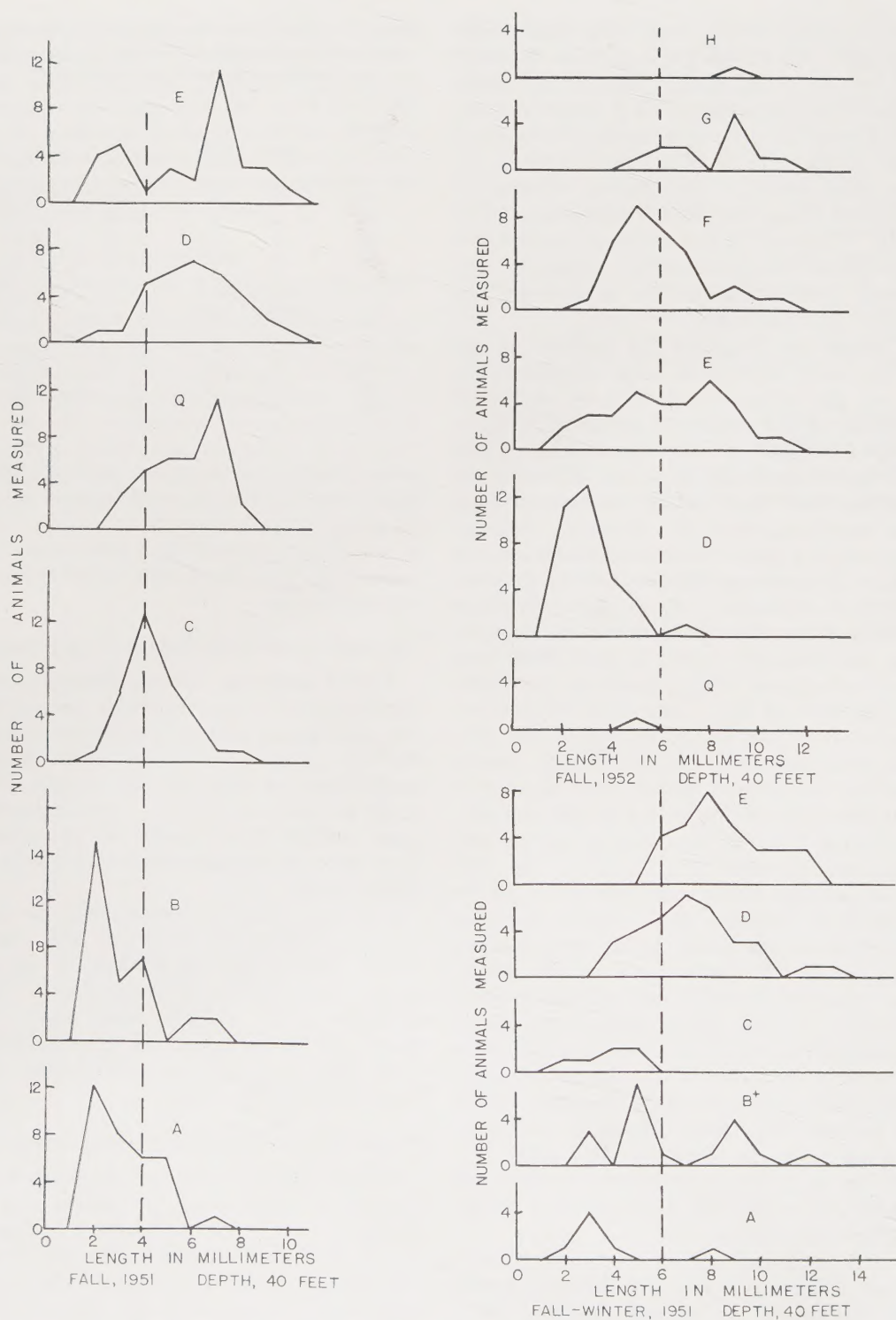


FIG. 4. Length-frequency diagrams of *Neomysis* at various stations during Cruises I, II, and VI (fall 1951, fall-winter 1951, and fall 1952, respectively).

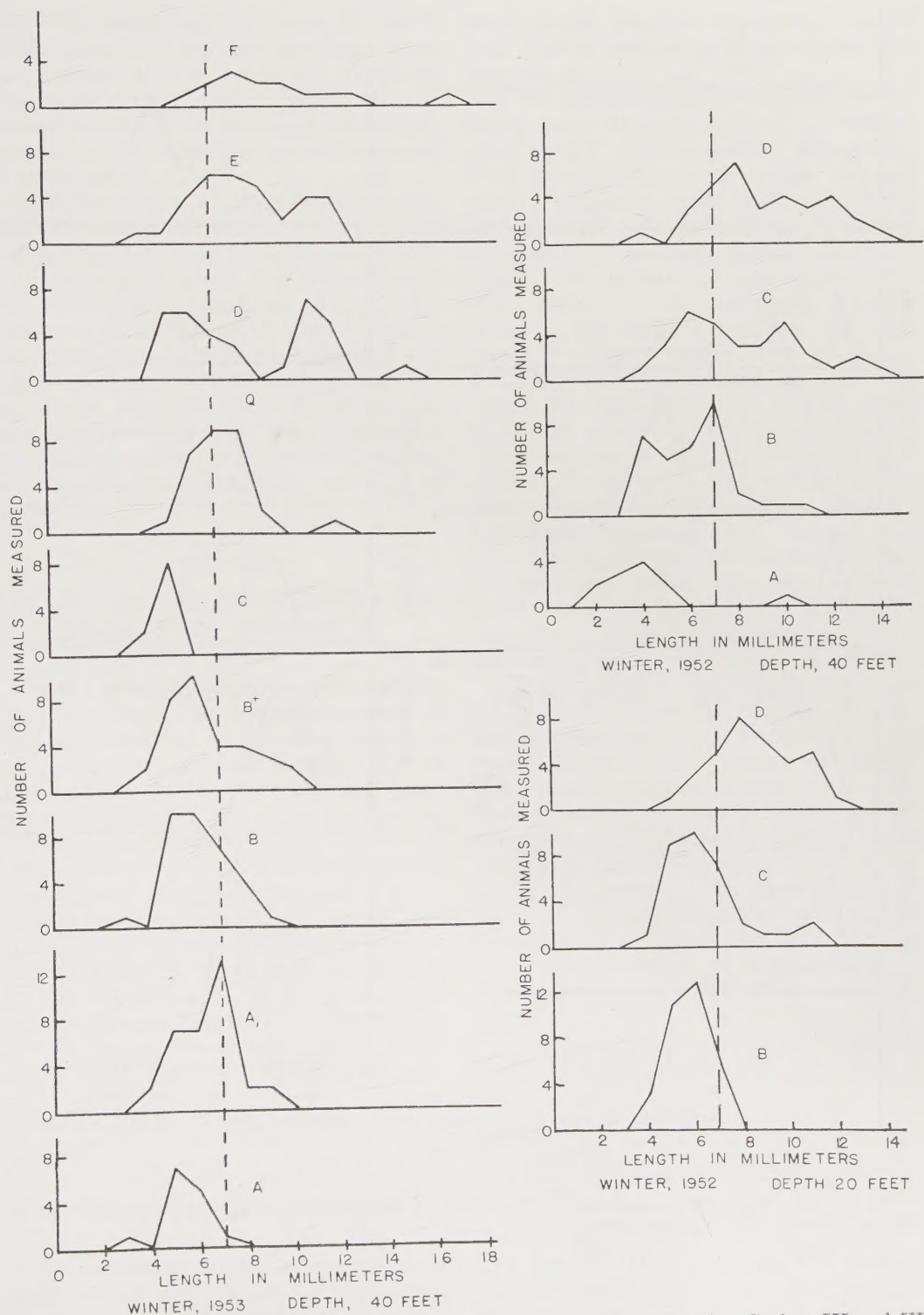


FIG. 5. Length-frequency diagrams of *Neomysis* at various stations during Cruises III and VII (winter 1952 and winter 1953, respectively).

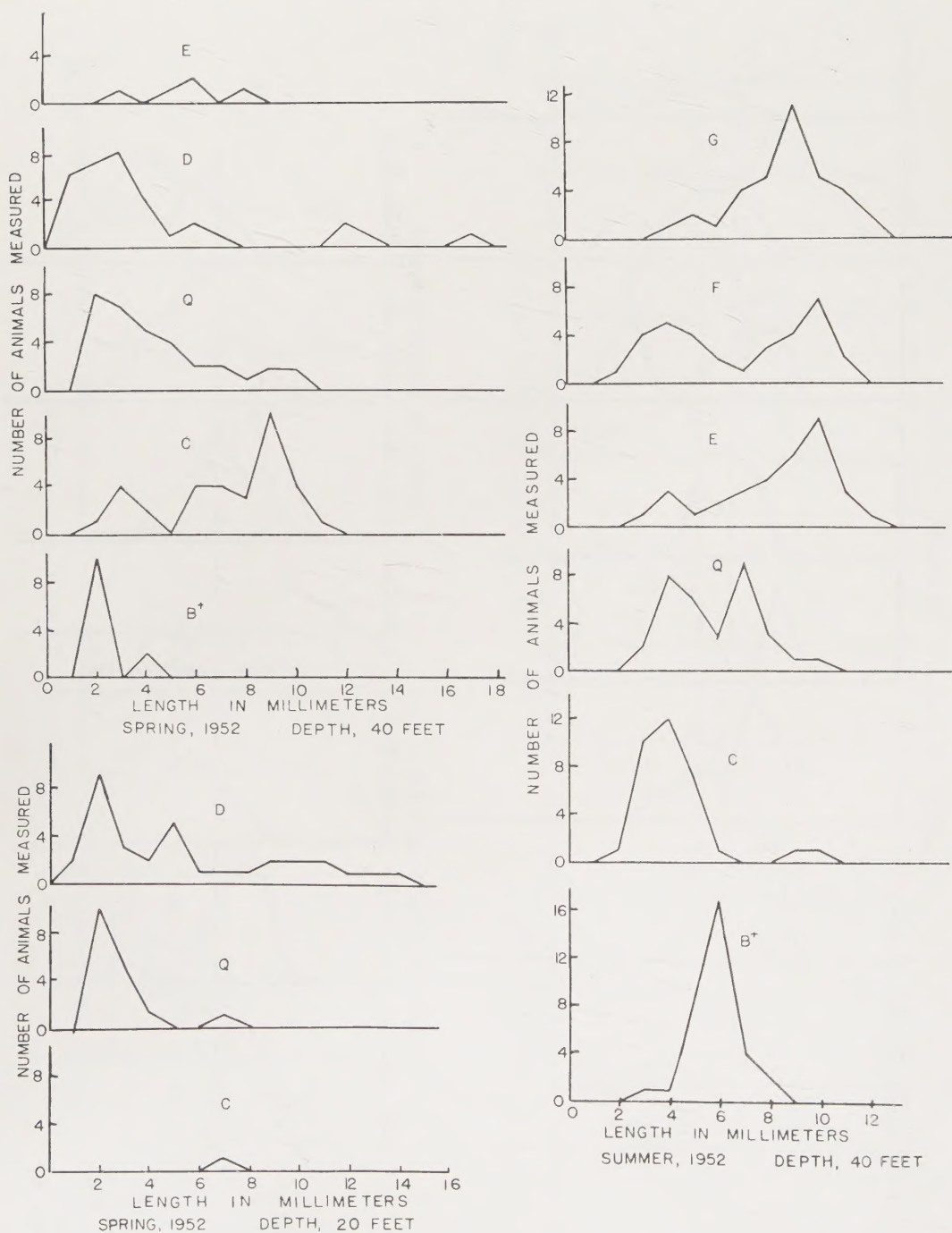


FIG. 6. Length-frequency diagrams of *Neomysis* at various stations during Cruises IV and V (spring 1952 and summer 1952, respectively).

tograms of Cruises I, II, III, VI, and VII, covering fall and winter, show that the population as a whole contained larger-sized animals toward the river end of the estuary.

Down-estuary a greater proportion of the population was smaller than the size represented by the dashed line, but up-estuary most of the animals were larger than this

size. The histograms for cruises IV and V of the spring and summer show that there was increase in size up-estuary for large individuals only. Small individuals did not become relatively less abundant up-estuary, as on the other cruises, but instead increased in abundance.

The histograms at 20 feet closely resembled those at the bottom (40 feet) on the winter cruise, III, and the spring cruise, IV.

In order to be certain that the change in size of the animals along the estuary was a distinct and true change, a statistical analysis of the lengths of animals on Cruise I was made. Using the *F*-test (Snedecor 1948), it was found that the mean length of the population at Station B⁺ was significantly less than that at Station C, where in turn the mean length was significantly less than at Station Q.

DISCUSSION

Effect of the circulation of the Delaware River estuary on the distribution of Neomysis americana

Table 2 gives two examples of the salinity distribution along the axis of the estuary of the Delaware River, one in spring and one in fall. The values are from samples taken at the beginning of the corresponding tows. The salinity profiles are similar in that the less saline water is at the surface and there is a gradual decrease of salt content up-estuary to water that is virtually fresh at a point between Stations F and I. The spring condition shows greater stratification and a lesser extension of salt water up the estuary than the fall condition. It will be assumed that the deep water in the main channel has a net movement up-estuary and the near-surface water has a net movement down-

estuary, and that this two-layered circulation extends farther upstream during fall than spring.

If this assumption of two-layered circulation is correct then the mysids in the bottom water might well be carried up-estuary. This consideration would explain the up-estuary increase in mean length during the cool months. While drifting up-estuary individuals of all sizes became older and larger. During the warm months two processes appear to be happening simultaneously. The large individuals not only continue to grow during their up-estuary drift but also produce young. By this means the large proportion of very small mysids far up-estuary, particularly in May, can be accounted for. In addition it was noticed during spring and summer cruises that everywhere in the estuary the large individuals frequently had thoracic egg sacs. Some of the sacs contained unliberated zoea rather than eggs. Cowles (1930) found the proportion of small individuals in Chesapeake Bay to be greater in the warm months, particularly in late spring.

The up-estuary increase in size of *Neomysis* in the deep water suggests that the population originated in the source salt water outside the Bay. This feature was particularly clear during cool months when reproduction within the estuary could not be detected. Bigelow and Sears (1939) point out that *Neomysis americana* is one of the regular inhabitants of the inner portion of the continental shelf between Cape Cod and Cape Hatteras. Thus, the chief area of origin—and therefore of reproduction—of *Neomysis* is probably the waters along the coast.

Irrespective of any reproduction occurring during the up-estuary drift, the greater

TABLE 2. Distribution of salinity at channel stations

Stations	A	A ₂	B	B ⁺	C	Q	D	E	F	G	H	I
% salinity in Spring, Cruise IV												
Surface	29.7	28.8	24.8	20.3	14.0	—	5.1	4.7	0.6	0.0	0.0	—
Bottom	30.8	29.3	25.2	24.5	23.7	—	19.1	15.6	3.5	0.0	0.0	—
% salinity in Fall, Cruise VI												
Surface	30.9	28.8	29.8	28.1	25.1	25.3	21.9	19.2	11.7	8.6	3.9	0.7
Bottom	31.8	29.3	30.2	28.3	26.0	26.0	23.8	20.2	13.1	9.1	4.5	0.9

TABLE 3. *The distribution of Neomysis at channel stations, expressed as number of animals per cubic meter*

Cruise	Stations							
	A	A ₃	B	B ⁺	C	Q	D	E
I	72.46	2.00	—	5.60	2.61	40.10	27.90	5.75
II	0.02	—	0.75	—	0.02	—	3.01	2.11
III	0.11	—	4.29	—	40.14	—	3.16	0.11
VI	0.00	0.00	—	0.01	0.00	0.02	0.33	4.74
VII	0.09	0.78	0.69	7.80	0.24	23.93	22.90	6.69

abundance of *Neomysis* was usually up-estuary, not down-estuary. If the source of the mysids is the salt water of the ocean, if the animals behave as a dissolved substance, and if they are not subject to any net reproduction or mortality, then the population should become attenuated up the estuary to the same degree that the salt water does. This was not found to be the case. —During Cruises I, II, III, VI, and VII no reproduction occurred in the Bay, and yet on four of these five cruises concentrations of *Neomysis* were larger up-estuary than down-estuary, between Stations A and E. This feature is shown in Table 3 in which the surface to bottom averages are given for each station. The most likely explanation is that although the deeper water carried mysids up the estuary, the animals were not carried from the deeper to the shallower levels by vertical mixing, and thus they were not carried out of the estuary in the outflowing surface waters. By their avoidance of the surface water the animals accumulated in the deeper water. Accumulation occurred along the length of the estuary up to the point where it is assumed that the two-layered circulation ended—where the salinity approached zero. It was pointed out that the location up-estuary where *Neomysis* abruptly decreased was farther up-estuary in summer and fall than in winter and spring. Isohalines varied in a similar way. The 4‰ isohaline appears to mark the general location of the up-stream end of the two-layered circulation and the resulting termination of mysid intrusion.

During the warm months the stock of animals would receive contributions by reproduction within the estuary. Hence, at

this time the abundance of *Neomysis* would be due in part to the process of accumulation and in part to reproduction.

Effect of light and salinity on the distribution of Neomysis americana

The observations at the mouth of the Bay over a 26-hour period indicated that *Neomysis americana* appears in the water only when there is very little light (at night) and disappears almost completely from the upper 60 feet of water during the bright light of day. The suggestion here that *Neomysis* avoids full daylight, seeking deeper, darker levels at that time, agrees with the great daytime vertical stratification at all channel stations. It agrees, too, with the rarity of the occurrence of this mysid in the surface waters of the margins of the Bay. It would appear, then, that light intensity is the controlling factor in the vertical distribution of *Neomysis*.

The maximum densities of *Neomysis americana* occurred nearer the surface at up-estuary stations than at down-estuary stations. At the same time, Secchi disc readings decreased up-estuary from a maximum value (average of all cruises) of 3.06 meters at Station A to 0.33 meters at Station G, a value representative of the minimal readings from there up-stream.

The depth of a critical light intensity, which would hold beneath it the heavy concentrations of mysids, was determined in the following manner. It has been pointed out that although surface concentrations of *Neomysis* were negligible or undetectable most of the time in the marginal area of the Bay, occasionally there were large concentrations. This feature suggests that in the deep or near-bottom water of the shallows there were at times heavy concentrations of mysids, which appeared at the surface on rare occasions. It will be assumed that the amount of light near the bottom on the shallows flanking Station C, where this feature was particularly noticeable, is a critical amount, larger amounts being unfavorable to *Neomysis*. When the amount of light entering the water surface is given the value of unity, the amount emerging at the bottom, I_e , depends approximately on

the depth in meters, z , and the Secchi disc reading in meters, S , as follows:

$$\ln I_c = -K \frac{z}{S}$$

The factor, K , has been found equal to 1.7 for oceanic and coastal waters having Secchi disc values ranging from 3.5 to 47 meters (Bumpus and Clarke 1947, Clarke 1941, Poole and Atkins 1929); even in a coastal bay, where S ranged between 0.3 and 2.1, K was 1.5 (Dr. John H. Ryther, personal communication). Using all Secchi disc readings at Station C-1 and C-5 average values of z , S , and $\frac{z}{S}$ were 3.50, 0.64, and 5.47, and I_c ranged between 0.5 and 3.0×10^{-4} of the surface light. At channel stations, which had progressively smaller values of S up-estuary, z was progressively smaller for $\frac{z}{S} = 5.47$. The values of z thus obtained and which mark the depth of the critical light intensity, I_c , are plotted as dashed lines along the length of the estuary in Figure 2. One can see that the large concentrations of mysids are generally located below this level of light intensity, which rises toward the surface up-estuary, paralleling a similar rise in the heavy concentrations of *Neomysis*.

In the river portion of the estuary where the water was completely fresh no specimens of *Neomysis* were found. In general, it is not a freshwater animal (Tattersall 1951). *Neomysis* was carried up to or somewhat beyond the 4‰ isohaline by the current system and was capable, therefore, of adapting to a wide range of salinities during this transit. Thus, the 4‰ isohaline and the critical light intensity, I_c , roughly mark horizontal and vertical limits to the spread of these mysid shrimps within the estuary.

It is interesting to compare *Neomysis americana* in the Delaware River estuary with *Limacina retroversa* in the Gulf of Maine (Redfield 1939). Within their re-

spective embayments the stocks of both animals were maintained by entrainment of populations produced outside the embayments. In the case of *Limacina* the populations are almost completely maintained by this means, but in the case of *Neomysis* they are maintained to some degree by reproduction within the embayment. The two animals represent intermediate types between the purely native animal and the rare, sporadic, immigrant.

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The Chemical Composition of Lake Waters in Halifax County, Nova Scotia¹

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ABSTRACT

Analyses for concentrations of total ions, Na, K, Ca, Mg, HCO₃, Cl, SO₄, and dissolved organic carbon, as well as optical density, pH, and specific conductivity, are presented for twenty-three surface lake waters collected from heathy spruce forest in Halifax County, Nova Scotia, during December 1955. As compared with the average fresh water of the world, these waters are very dilute, and proportionally low in calcium bicarbonate while high in sodium chloride. The three main factors governing chemical composition are shown to be (1) the nature of the geological substratum, (2) the influence of topography as expressed in the accumulation of mineral sediments and peat in and around the lake basins, and (3) proximity to the sea.

INTRODUCTION

Analysis of the ionic composition of dilute lake waters has until recently been a matter of some difficulty, so that the supply of the major dissolved constituents to such waters has received relatively scanty attention from limnologists. This paper records concentrations of total ions, Na, K, Ca, Mg, HCO₃, Cl, SO₄, and dissolved organic carbon, as well as optical density, pH, and specific conductivity, in a series of rather dilute surface lake waters collected from heathy spruce forest in Halifax County, Nova Scotia, during the cold dry weather of December 1955, when the lakes were under thick snow and ice cover.

The samples include both clear and peaty waters, from lakes on three main geological substrata—an intrusive granite batholith, the metamorphic Meguma gold-bearing series of slate overlying quartzite, and carboniferous strata of the late Mississippian

period. The general physiography of the area, in relation to the underlying geology, is discussed by Goldthwait (1924). The lakes fall into four main size ranges: very small ponds (nos. 3, 5, 18 and 19 in Table 1), small lakes of from 1 to 10 hectares (nos. 2, 6, 7, 8, 9, 10, 11, 20, 21, 23), medium-sized lakes of about 20 to 30 hectares (nos. 13, 14, 15, 22), and larger lakes of more than about 50 hectares (nos. 1, 4, 12, 16). However, none of the chemical properties examined shows any obvious relation to lake area.

While surveys of macro-vegetation have only been carried out on four of the granite lakes, it may be of interest to point out the following species as among those most frequently encountered during a brief survey of these and other similar lakes in 1946 and subsequent years:

Eriocaulon septangulare

Lobelia dormanna

Dulichium arundinaceum

Pontederia cordata

Nymphoides cordatum

Nuphar variegatum

Nymphaea odorata

Sparganium fluctuans

Potamogeton spp. (most commonly *P. epihydrus* var. *nuttallii*)

Scirpus subterminalis

Chamaedaphne calyculata

Sphagnum spp.

Of these, the first two are perhaps more characteristic of the less organic substrata, while the last two indicate peaty conditions,

¹ The writer is most grateful to Professor F. R. Hayes of Dalhousie University, who kindly invited him to undertake this study, and provided laboratory facilities and transport. Thanks are also due to the Director of the Nova Scotia Research Foundation, Dr. H. D. Smith, for the financial support accorded by the Foundation. The rain sulfur analyses quoted were provided through the courtesy of Mr. F. A. Herman, of the Dominion Experimental Station at Kentville, N. S. Lastly, Mr. F. J. H. Mackereth has given much helpful advice on analytical procedures, especially with regard to organic carbon and optical density measurements.

and often the presence of a floating bog mat around the lake margins.

The zooplankton organisms most frequently met with in these surveys were as follows:

Diaptomus minutus
Diaptomus spatulocrenatus
Mesocyclops leuckarti
Bosmina longispina
Diaphanosoma brachyurum
Daphnia pulex
Holopedium gibberum
Polyphemus pediculus

By far the most common fishes were *Fundulus diaphanus* and *Salvelinus fontinalis*.

METHODS

The waters were collected through the ice in polyethylene bottles, filtered through Whatman 54 filter papers (washed with three volumes of distilled water and one volume of sample) on return to the laboratory, and stored in the original bottles until analyzed. Specific conductivity was measured with bright platinum electrodes, and pH by glass electrode, both before and after aeration with compressed air until drift ceased. Na and K were estimated without concentration by EEL flame photometer using Calor-gas fuel. Ca and Mg were determined by versenate titration according to the method of Heron and Mackereth (1955). The anions were measured conductimetrically following the ion-exchange procedures developed by Mackereth (1955), HCO_3^- being estimated as the difference between total metal cations and strong acid anions. The slight differences observed in samples below pH 5.7 (the pH of distilled water in equilibrium with atmospheric CO_2 at 25° C) were attributed to experimental error, since there was no clear relation between the amount of difference and pH. Total metal cations as estimated by this procedure corresponded very closely to the sum of the four metal cations analyzed individually. SO_4 values by this method include small amounts of NO_3^- , which are most unlikely to be of any significance in this type of lake water, according to experience in this laboratory.

Dissolved organic carbon was determined by a new wet oxidation method devised by Mackereth in this laboratory and as yet unpublished. While the samples were filtered through a no. 3 sintered glass plate (average pore size 20–30 μ), some filter-passing substances will no doubt be included with the dissolved organic materials. Optical densities were measured at 320 $m\mu$ in the above waters, by means of a Unicam SP 500 spectrophotometer with 10 cm glass tubes and slit widths of about 0.5 mm. In addition, absorption spectra were determined between 320 and 700 $m\mu$ by the same instrument, on both the clearest and the most highly colored of the lake waters, again using glass tubes, and slit widths varying from about 0.5 mm at 320 down to 0.025 mm at 700 $m\mu$. Lastly, it was noticed that on standing the bottoms of some of the sample bottles became spotted with orange-brown colonies of iron bacteria, resembling the agar plates used for bacterial counts. The density of such iron precipitates was recorded visually in three grades.

RESULTS

The analytical data are presented in Table 1, the waters being arranged in order of increasing total ion concentration within three main groups separated according to the nature of the underlying rocks. Since the Meguma quartzite and slate lake waters show no clear chemical differences, they have been grouped together. All lakes receiving drainage from carboniferous rocks have also been grouped together, although Fraser Lake, wholly on quartzite, is transitional in its chemical properties. Results are expressed in parts per million (ppm), with the exception of pH, specific conductivity (as reciprocal megohms at 20° C), total ions (as milli-equivalents per litre), and optical density $\left(\text{as } \log \frac{I_0}{I}\right)$. The positions of the lakes on the map are also given in Table 1, and their locations are shown in Figure 2. Where "normal" lakes are referred to, the two quarry ponds and the two senescent lakes almost filled in by sediments are excluded.

TABLE 1. Chemical composition of some lake waters from Halifax County, Nova Scotia

Number	Name	Map position		Specific conductivity mhos·10 ⁶ 20°C	Total ions m-equiv. per L	pH		Na	K	Ca	Mg	HCO ₃	Cl	SO ₄	Dissolved organic carbon	Optical density log $\frac{I_0}{I}$	Bacterial iron precipitates
		W	N			Before aeration	After aeration										
On Granite																	
1	Hubley's Big Lake (peaty arm)	63°50'	44°39'	31	0.24	4.84	4.84	3.4	0.4	1.0	0.2	nil	4.9	4.2	7.2	not done	—
2	Railway Pond	63°52'	44°41'	28	0.25	5.22	5.36	3.4	0.4	1.1	0.4	nil	4.8	4.6	5.2	0.49	++
3	Punchbowl	63°48'	44°41'	35	0.29	4.79	4.82	4.2	0.4	1.1	0.3	nil	5.5	5.6	9.8	1.87	—
4	Long Lake	63°38'	44°37'	38	0.30	4.82	4.84	4.0	0.5	1.1	0.6	nil	6.0	5.4	4.2	0.53	—
5	Purcell's Cove Granite Quarry	63°35'	44°36'	41	0.32	4.85	4.89	3.4	0.5	1.8	0.6	nil	5.6	8.5	1.2	0.21	—
6	Bluff Lake	63°39'	44°33'	39	0.32	5.12	5.28	4.9	0.3	0.9	0.6	nil	8.1	4.5	2.5	0.18	—
7	Silver Lake	63°39'	44°33'	51	0.40	4.46	4.47	5.7	0.4	1.1	0.6	nil	7.9	7.5	11.6	1.76	—
8	Purcell's Pond	63°35'	44°36'	74	0.41	3.95	3.95	5.0	0.3	0.8	0.4	nil	7.2	9.5	11.1	1.74	—
9	Black Lake	63°39'	44°31'	53	0.41	4.50	4.55	6.4	0.4	1.0	0.6	nil	9.9	5.6	7.9	1.27	—
10	Duncan Lake	63°32'	44°30'	70	0.57	4.58	4.63	9.5	0.6	0.8	1.0	nil	15.2	6.4	7.5	1.17	—
On Gold-Bearing Series ¹																	
11	Mt. Uniacke Gold Mines Lake	63°49'	44°55'	28	0.25	5.94	6.66	2.4	0.6	2.1	0.3	3.2	3.8	4.1	6.7	0.68	++
12	Webber Lake	63°43'	44°46'	30	0.27	5.38	5.50	3.0	0.5	1.8	0.4	nil	4.5	5.2	9.5	1.23	+
13	Lewis Lake	63°46'	44°49'	33	0.28	4.96	5.00	2.9	0.4	1.9	0.4	nil	4.8	5.6	10.3	1.32	++
14	Tucker Lake	63°41'	44°51'	32	0.30	6.45	6.93	2.7	0.6	2.4	0.5	4.0	4.7	4.5	3.9	0.43	—
15	Baptizing Lake	63°46'	44°44'	34	0.30	5.76	6.04	3.4	0.7	1.7	0.5	1.8	5.6	5.2	5.3	0.56	+
16	Fish Lake	63°37'	44°46'	33	0.31	6.17	6.92	3.0	0.4	2.7	0.4	3.8	4.9	5.2	2.8	0.29	—
17	Sandy Lake	63°42'	44°44'	40	0.33	5.02	5.18	3.8	0.7	1.8	0.6	nil	6.3	6.8	7.1	0.73	—
18	Purcell's Cove Slate Quarry	63°34'	44°37'	45	0.38	4.89	4.92	4.6	0.7	1.4	1.1	nil	7.3	7.9	<0.5	not done	—
19	Mt. Uniacke Gold Mines Pond	63°49'	44°56'	44	0.42	6.60	7.24	2.8	0.4	4.9	0.5	11.6	4.8	4.5	3.8	0.41	+++
On or Receiving Drainage from Carboniferous Strata ²																	
20	Fraser Lake	63°00'	45°05'	31	0.30	6.44	6.90	2.8	0.3	2.6	0.5	4.6	4.1	4.8	9.3	1.15	—
21	Crossgill Lake	63°11'	45°08'	36	0.36	6.60	7.10	2.8	0.6	3.2	0.7	7.6	4.3	5.5	8.7	1.04	+
22	Brine Lake	63°55'	44°37'	48	0.44	6.38	7.09	5.3	0.6	3.1	0.7	6.1	7.8	5.6	4.7	0.45	—
23	Nelson Lake	63°03'	45°05'	52	0.51	6.70	7.50	2.5	0.6	5.6	1.2	16.3	3.8	7.4	4.8	0.64	+

¹ Lakes no. 11, 13, 16 and 19 on quartzite; nos. 15 and 17 on quartzite with some drainage off slate; nos. 14 and 18 on slate; and no. 12 on slate with some drainage off quartzite.

² Lake no. 20 on quartzite, receiving some drainage from carboniferous rocks; no. 22 partly on granite and partly on carboniferous strata.

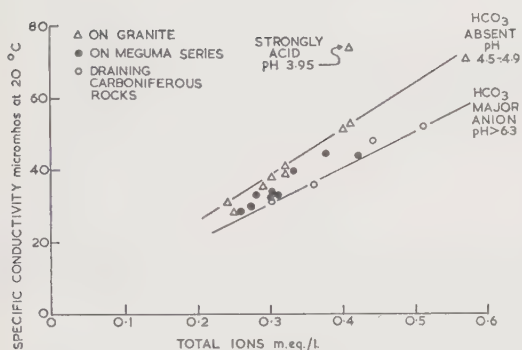


FIG. 1. The relation between specific conductivity and total ionic concentration in waters from Halifax County, Nova Scotia.

Total ions and specific conductivity

The ranges of specific conductivity and total ions are in general rather similar for the three geological groups of lakes, the median values for all lakes lying at 38 and 0.32 m. equiv./L, respectively. In the granite series the water richest in salts came from Duncan Lake, situated on an exposed headland very near the sea, and hence high in NaCl. In the other two geological groups the richest waters came from shallow lakes nearly filled in with mineral and organic sediments. These waters yielded high concentrations of $\text{Ca}(\text{HCO}_3)_2$, probably released from the bottom materials by weathering.

The relation between specific conductivity and total ions is rather close, although a certain variability is evident in Figure 1. The very acid water from Purcell's Pond, along one edge of which is found a large *Sphagnum* bog, exhibits a much greater specific conductivity (74) than would be inferred from the total ion concentration of 0.4 m.equiv./L, for which the usual conductivity is about 40–50. The extremely high equivalent conductivity of the hydrogen ion is responsible for this anomaly, for which a correction can easily be made (Sjörs 1950). Again, the moderately acid lakes with no HCO_3^- show higher specific conductivities than those which are only faintly acid and have HCO_3^- as the main anion. Another factor involved here is the relatively low

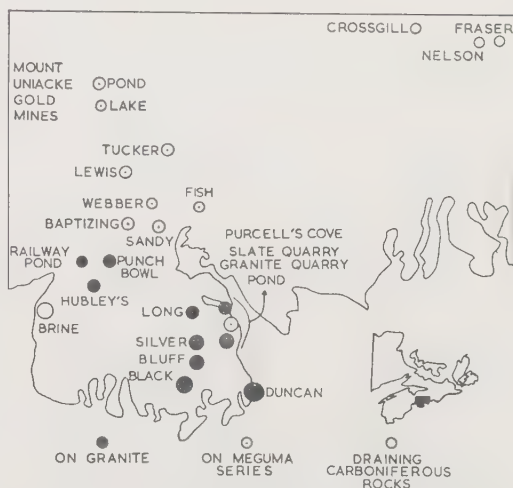


FIG. 2. The locations of the waters sampled, and the influence of proximity to the sea upon chloride concentrations. (The areas of the circles are proportional to chloride concentrations.)

equivalent conductivity of the HCO_3^- ion as compared with Cl and SO_4 ions.

Chloride, sodium and magnesium

Figure 2 shows clearly that the higher Cl concentrations occur nearest the coast. Since the granite lakes occupy the coastal belt their waters are highest in Cl. Within the other two geological groups the maximum Cl values also come from those lakes nearest the sea. The close adherence of the Na and Cl values to the line (Fig. 3) showing sea-water proportions suggests that by far the greatest part of these ions comes as sea spray in atmospheric precipitation (cf. also Conway 1942, Gorham 1955a, Eriksson 1955). The slight excess of Na may be presumed to come from rock-weathering. In this connection it may be noted that

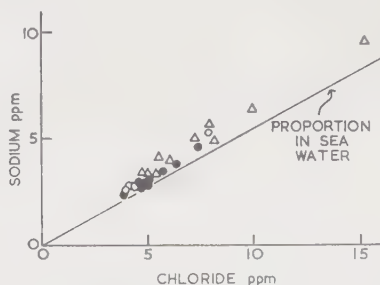


FIG. 3. The relation between sodium and chloride

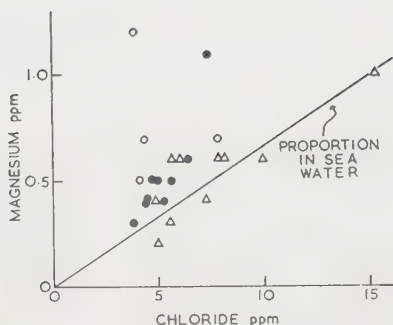


FIG. 4. The relation between magnesium and chloride.

among the "normal" lake waters those from the Meguma quartzites and slates show less excess Na than either the granite or carboniferous series, which resemble one another in this respect. The average Na/Cl ratio in sea water is 0.55, in the quartzite waters 0.61, and in both the other types 0.67.

Magnesium is also supplied to a marked extent from the sea, with the granite waters showing a Mg/Cl ratio the same as that of sea-water (0.067). However, as shown in Figure 4 the Meguma series, and especially the waters draining carboniferous strata, exhibit considerable enrichment in Mg, presumably from weathered rock and soil minerals.

Among the lakes on granite, Duncan yields the highest Mg concentration (1.0 ppm), again because of its proximity to the sea. The highest Mg/Cl ratio in this group (0.11), however, comes from the Purcell's Cove granite quarry pond, where presumably more Mg than usual is released by breakdown of the freshly exposed rocks. On the gold-bearing series the Purcell's Cove slate quarry provides an even higher Mg/Cl ratio (0.15), and the absolute concentration is also high (1.1 ppm). The greatest mineral enrichment of Mg is shown by the senescent Nelson Lake on carboniferous rocks (Mg 1.2 ppm, Mg/Cl 0.32).

Potassium

Only a small part (on the average about 0.1 ppm) of the K in these lake waters can have been supplied from the sea (K/Cl ratio in sea-water 0.02), and the remainder (averaging 0.5 ppm) must come from the

rocks and soils, much of it perhaps as atmospheric dust. Waters on the Meguma rocks are in general richest in K, and waters on granite poorest, although the differences amount to less than 0.2 ppm on the average.

Calcium and bicarbonate

Calcium is supplied to these lakes almost wholly by rock and soil weathering, the sea spray contribution calculated from Ca/Cl ratio (0.02) again averaging about 0.1 ppm. There is a distinct difference between the three geological groups in respect of Ca, the "normal" lake waters averaging about 1, 2, and 3 ppm on the granite, Meguma, and carboniferous rocks, respectively. The Ca levels in the granite lakes are not far different from those observed in the British Isles in raised and blanket bog pools completely isolated from mineral soil influence and wholly dependent upon atmospheric sources of supply such as dust fall (Gorham 1956), so that Ca release from the granite rocks may be presumed to be extremely slow. It is of interest that Silver Lake was fertilized in 1947 with about 2200 kilograms of basic slag and in 1948 with 500 kg of superphosphate, while Black Lake received 1100 kg of basic slag plus 300 kg of superphosphate in 1948. After seven years neither of these lakes differs from other similar granite lakes in respect of either Ca or pH. Also notable is the fact that Brine Lake, on the edge of a tiny enclave of carboniferous rocks surrounded by granite, manages to maintain its chemical identity with the other carboniferous lakes.

Differences are also evident in the HCO_3 concentrations of the three types of lake, this ion being absent from all the waters on granite, present in all the waters draining carboniferous strata, and present in five of the nine waters on the Meguma quartzites and slates. Only in the circumneutral waters is there a clear correlation between Ca and pH after aeration (see Fig. 5), which is paralleled by a similar relation between these two variables and HCO_3 .

The two waters highest in Ca and HCO_3 are from the two senescent lakes nearly filled by sediments, from which there is almost certainly a release of $\text{Ca}(\text{HCO}_3)_2$ to

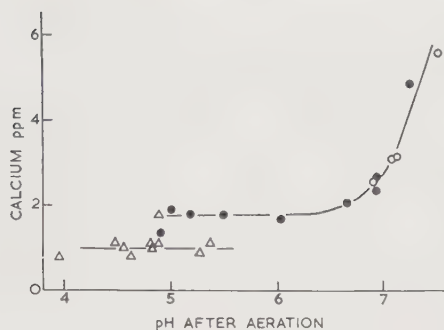


FIG. 5. Calcium and acidity in waters draining three types of geological substrata.

the water above, through the action of normal weathering processes. Of the Meguma lakes, those richest in Ca lie along the north-east border of the area sampled, nearest to the carboniferous zone, and farthest from the granites. The largest concentration of Ca in the granite waters was observed in the quarry pond at Purcell's Cove, and at 1.8 ppm was almost double the average value. The slate quarry on the other hand yielded a lower value (1.4 ppm) than the average for the Meguma waters.

Acidity

At higher pH levels an appreciable proportion of the acidity in these lake waters is due to dissolved CO_2 , which can be mostly removed by bubbling with compressed air (see Table 1). However, the pH is largely governed by the amount of $\text{Ca}(\text{HCO}_3)_2$ added to the lake waters from weathering minerals, as shown above. Toward the acid end of the scale, the lowering of pH is associated with increasing concentrations of SO_4 and (with the exception of the quarry ponds) of organic matter, as illustrated in Table 2. This table also shows that at similar SO_4 levels the Meguma lakes are less acid than those on granite, which is presumably connected with the higher calcium concentrations in the former.

Using the pH of distilled water in equilibrium with the atmosphere at 25°C (pH 5.7) as a dividing point, acid waters can be separated from circumneutral waters; and in fact these two groups are quite sharply separated, since only one of the twenty-three waters falls within the pH range

TABLE 2. The pH of waters on granite and on the Meguma Gold Bearing Series in relation to sulfate and organic carbon concentrations. pH values in brackets are from quarry ponds.

Organic Carbon ppm	Lakes on granite				Lakes on Meguma quartzites or slates			
	Sulfate ppm				Sulfate ppm			
	4-5	5-6	6-8	> 8 ppm SO_4	4-5	5-6	6-8	> 8 ppm SO_4
0-2				(4.9)				(4.9)
2-4	5.3				7.2	6.9		
					6.9			
4-6	5.4	4.8				6.0		
6-8	4.8	4.6	4.6		6.7		5.2	
8-10		4.8				5.5		
10-12			4.5	4.0		5.0		

TABLE 3. A comparison of acid and circumneutral waters

	Ionic concentrations (m.equiv./L)			
	H	SO_4	Ca	HCO_3
Acid waters	0.021	0.131	0.063	nil
Neutral waters	trace	0.108	0.157	0.108
Difference	0.021	0.023	0.094	0.108

5.5-6.5. While all the waters on granite are acid, and on the carboniferous rocks circumneutral, the Meguma group is evenly divided between these two classes. It is now instructive to compare the equivalent levels of hydrogen ions, SO_4 , Ca, and HCO_3 in these acid and neutral waters, as set out in Table 3. At once apparent is the even balance between the hydrogen ions of the acid group and the excess of SO_4 in this as compared with the circumneutral series (hydrogen ions 0.021 m.equiv./L, SO_4 excess 0.023 m.equiv./L). Thus it may be inferred that the acidity of these lake waters is due mainly to sulfuric acid. Moreover, about nine-tenths of the HCO_3 ions in the neutral waters are balanced by the excess of Ca in this group, which suggests that these lakes are more strongly influenced by rock and soil weathering.

It is worth noting that both the acid and circumneutral waters show rather wide ranges of organic carbon concentration, although the acid series includes more of the highly organic samples.

Sulfate

Of the average level of 5.6 ppm SO_4 in all the "normal" lake waters, only about 0.9 ppm can have come as SO_4 from sea-water ($\text{SO}_4/\text{Cl } 0.14$), although it has been suggested by Conway (1942) and others that H_2S may diffuse from the muds of the continental shelf into the atmosphere and be oxidized there, later to come down in atmospheric precipitation.

Sphagnum bog peats accumulate sulfur from the atmosphere, and may release it as sulfuric acid (Gorham 1956), which probably provides the source of acidity in these Nova Scotian waters, many of which drain, or are bordered by, *Sphagnum* peats. For instance, among the granite lakes Purcell's Pond has a large peat bog immediately along one side, and Silver Lake a smaller one, while the Punchbowl is entirely surrounded by a *Sphagnum* mat. And the most acid water on the Meguma gold-bearing series is that of Lewis Lake, which appears from the map to drain large areas of peaty swampland. Webber Lake, also acid, is part of the Sackville River system, which in its upper reaches appears to run through extensive stretches of swampy land. Such a mode of supply could account for the inter-correlations between pH, SO_4 , and organic carbon shown in Table 2. However, since even the clearest lake waters contain more than 4 ppm of SO_4 , the addition of sulfuric acid from peat cannot by any means provide the main supply of this ion. That rain is a major source of SO_4 for these lake waters is suggested by recent analyses of Herman (unpublished), who found an average of 0.96 ppm total sulfur, equivalent to 2.9 ppm SO_4 , in rain collected over a two-year period at the Dominion Experimental Station, Kentville, N. S. Moreover, rain SO_4 would be concentrated somewhat before reaching the lakes, owing to evaporation, so that this value represents a minimum for the rain contribution to lake water concentrations.

Other possible sources for SO_4 in these lake waters are the often rather organic bottom deposits, where sulfur may accumulate in organic debris. Anaerobic decomposition frequently produces H_2S in these

sediments, and this is free to diffuse into the overlying water and become oxidized to H_2SO_4 when oxygen is present.

Most rocks contain much less sulfur than alkali and alkaline earth metals, and have generally been thought unlikely to be a major source of supply to fresh waters. However, it may be noted that in the present case the quarry ponds, with very little organic matter in their waters, both exhibit high SO_4 concentrations, and the slate quarry pond yields the most acid water among those on the gold-bearing series. The slates round about Halifax are often rich in iron pyrites, which may be the source of the observed acidity. It is also interesting that in the lakes draining carboniferous strata there is a clear correlation between SO_4 on the one hand and Ca and HCO_3 on the other. This may be taken to suggest that a little CaSO_4 as well as CaCO_3 is being weathered from these rocks.

Organic carbon

The lowest concentrations of dissolved organic carbon are found in the quarry ponds, while the "normal" lakes vary from 2.5 ppm in the very clear water of Bluff Lake to around 10 ppm in lakes like Lewis, Webber, Silver, Purcell's Pond, and the Punchbowl, all in peaty surroundings. Both high and low levels are encountered on all three rock types.

As might be expected, optical density in these lake waters (at 320 $\text{m}\mu$) is closely re-

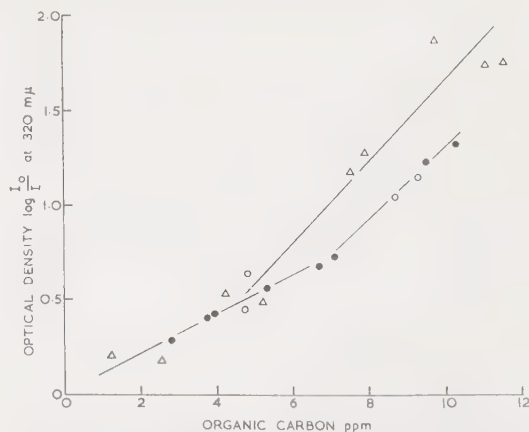


FIG. 6. The relation between optical density and organic carbon concentration.

lated to organic carbon concentration. However, the relationship is not strictly linear, and Figure 6 shows that the most organic waters exhibit proportionally greater optical densities than those with a low carbon content. Moreover, the peaty waters from granite lakes appear to be more highly absorptive than those from lakes draining Meguma or carboniferous rocks, with similar concentrations of carbon. It is reasonable to suppose that this may be connected with the type of vegetation from which the organic matter is derived, and with its mode of decomposition. The water giving the highest ratio of optical density to carbon (0.19) is that from the Punchbowl, which is wholly surrounded by a *Sphagnum* mat growing out from deep *Sphagnum* peat; and high ratios are also shown by Silver Lake (0.15) and Purcell's Pond (0.16), where *Sphagnum* peat is abundant in the vicinity. In contrast, the peaty areas draining into Webber and Lewis Lakes, which show relatively lower ratios (0.13), seem from the map more likely to be sedge swamps, being largely developed along the margins of the Sackville River system. At any rate, they seem unlikely to be as strongly dominated by *Sphagnum* as the peats beside the granite lakes mentioned, which are all characteristic of sites where there is little mineral soil influence, and fairly stagnant conditions predominate. Among the lakes draining carboniferous strata the senescent Nelson Lake yields the highest ratio of optical density to carbon (also 0.13). This lake is certainly still in the phase of marginal fen colonization, without much formation of *Sphagnum* peat.

The lowest ratio (0.07) comes from Bluff Lake, with the least organic carbon among the "normal" lake waters. It is not inconceivable that in this instance the organic material is derived more from organisms within the lake, which are certainly of different chemical composition from *Sphagnum*, sedges, or coniferous forest plants, and are quite probably susceptible to different types of breakdown.

Adjustment of an acid water from Black Lake to pH 7.0 had no significant effect upon the light absorption at 320 $m\mu$, nor did

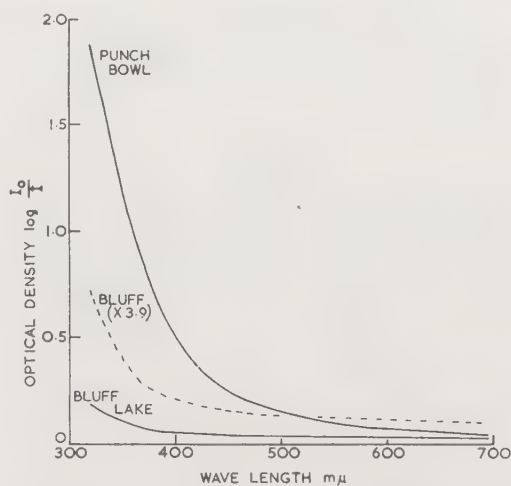


FIG. 7. Light absorption by a highly colored water with much organic carbon, from the Punchbowl, as contrasted with a very clear water low in organic carbon, from Bluff Lake.

acidification of Fraser Lake water to pH 4.8, the middle of the acidity range for the present series of lakes.

To provide further information concerning light absorption in these lake waters, the spectra of Bluff Lake and the Punchbowl were measured between 320 and 700 $m\mu$. Figure 7 illustrates the great increase of absorption in both waters with decreasing wave length. If the Bluff Lake values are multiplied by a factor of 3.9, the ratio of organic carbon contents in the two waters, it is evident that the Punchbowl has a relatively greater absorption at the lower wave lengths, and Bluff Lake at the higher wave lengths. Dilution of the Punchbowl water

TABLE 4. A comparison of the proportions of major ions in Nova Scotian lake waters and in the average fresh water of the world

Lake type	Ionic proportions (m.equiv. %)							
	H	Na	K	Ca	Mg	HCO ₃	Cl	SO ₄
On granite	8	62	3	14	12	—	64	36
On quartzite and slate	1	46	5	36	13	11	50	39
Draining carboniferous strata	—	42	3	40	14	28	42	30
Average fresh water of the world	—	16	3	64	17	74	10	16

to one-tenth concentration decreased absorption to 10.5 per cent of the original at 320 $m\mu$, and to 7.9 per cent of the original at 500 $m\mu$.

DISCUSSION

Examination of the equivalent composition of "normal" lake waters receiving drainage from the three geological substrata investigated here reveals striking differences from the world average composition of fresh water (Conway 1942, Rodhe 1949), as illustrated in Table 4. The Nova Scotian waters are proportionally much richer in Na and Cl, much poorer in Ca and HCO_3 , and more acid than the world average, which reflects the abnormal balance in Nova Scotia between the supplies of sea spray and rock weathering products, the former being somewhat high and the latter extremely low, particularly on the granites.

From the results of the present survey, it can be seen that the main factors affecting ionic composition in these lake waters are (1) the nature of the geological substratum, (2) the influence of topography as expressed in the accumulation of both mineral sediments and peat in and around the lake basin, and (3) proximity to the sea.

In connection with geological influences, the levels of Ca and HCO_3 in the Meguma lakes present certain problems. Quartzite is generally considered to be one of the most infertile soil parent materials, slow in weathering, and usually lower in lime even than granite. Moreover, the local quartzite terrain is described by Goldthwait (1924) as closely resembling that of granite, and similarly barren. On the other hand, he remarks that slate yields a much more productive and fertile landscape. From this account one might expect the quartzite lakes to resemble the granite lakes in their calcium and acidity levels, rather than the other Meguma lakes on slate, to which they do correspond in fact.

The rather high Ca and HCO_3 status of Fish, Tucker, and Mt. Uniacke Gold Mines Lakes relative to the others on the Meguma series is also difficult to account for. Since Fish and Tucker Lakes lie close to the axis

of the great Shubenacadie Grand Lake valley which runs south from the softer rocks of the Hants-Colchester Lowlands, they may have received drift richer in lime from the ice-sheets moving southward along this route during the last glacial period. And Gold Mine Lake may also have acquired such material during the southeastward advance of the ice from New Brunswick. At present, unfortunately, evidence to support these speculations is wholly lacking, and it is obvious that the factors determining the lime content of the Meguma waters require a good deal of elucidation. Studies of soil profiles, both mineralogical and chemical, would be of much interest in this connection.

The chief value of the present survey may perhaps lie in the provision of a background for further ecological studies. Primary differences are clearly evident in both calcium concentration and acidity of waters on the three types of geological substratum, and since the lime concentrations in all three groups are extremely low in comparison with most fresh waters, it would be very surprising if there were not associated differences in soil profiles and vegetation, both within the lakes and in their drainage basins. It might also be worthwhile to look for differences in organic production, with particular reference to the production of trout for angling. A comparison of peaty and clear waters might also be of interest here.

A last point to be remarked is that all these areas have probably been subjected to repeated burning and cutting, and have in consequence suffered a good deal of soil degradation and vegetational change within historical times (cf. Smith 1835, as quoted by Gorham 1955b). Such factors may well have influenced lakes in these areas.

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The Ionic Composition of Some Lowland Lake Waters from Cheshire, England

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ABSTRACT

Analyses are presented for the major dissolved constituents in waters from nine Cheshire meres. Calcium and bicarbonate ions predominate, but there are also large proportions of magnesium, sodium, sulphate, and chloride in these rather concentrated waters. The two lakes lacking inflow and outflow streams are chemically aberrant, and it appears that their ionic composition is greatly influenced by that of rain. The chemistry of the normal mere waters reflects the arid conditions in which the underlying Keuper marls were deposited.

INTRODUCTION

In studies of British fresh waters there has been a marked tendency to concentrate upon the predominantly upland areas of older and harder rocks, and in particular a good deal is known of both the physical background and the biology of waters in the English Lake District (Macan and Worthington 1951). In contrast, the lowland lakes have received rather little attention, apart from scattered floristic and faunistic investigations. However, some of the Cheshire meres have recently been examined by Lind (1944, 1951; Lind and Galliford 1952), chiefly with a view to ascertaining the composition of the phytoplankton and the factors influencing it; and it seemed worthwhile to inquire into the chemistry of these waters in some detail, not only in the hope that it would lead to some further understanding of such lowland waters, but also to provide some comparison with the relatively well-known waters of the Lake District (Mackereth 1957).

My thanks are due to Dr. H. B. N. Hynes for collecting several of the samples, and providing notes on the sites; and to Mr. P. Hamer for the other samples. Mr. J. Heron kindly made the analyses for nitrate, phosphate, and silica.

SITES INVESTIGATED

The samples analyzed came from nine bodies of water near Northwich: a small lake near Sandiway, Oak Mere, Whitegate

New Pool, Hatch Mere, Budworth Pool, Rostherne Mere, Tatton Mere, Pick Mere, and Budworth Mere. They range in size from 1–2 acres (Sandiway) to 100 acres (Rostherne), and in altitude from about 240 feet (Sandiway, Oak, and Hatch Meres) to 60 feet (Budworth Mere). All lie on Triassic substrata (Keuper marl and Rhaetic beds), but the drift shown on the 1" Geological Survey maps ranges from glacial sands and gravels (e.g. Sandiway, Oak, and Hatch Meres) to boulder clay and alluvium (e.g. Pick and Budworth Meres). Oak Mere and the lake at Sandiway differ from the others in being without either inflow or outflow streams. Budworth Pool has a strongly polluted inflow.

The phytoplankton of Oak, Hatch, Rostherne, and Budworth Meres has been studied by Lind (1944) and others. It is, with the exception of Oak Mere, characterized in general by large numbers, but relatively few species, of blue-green algae, and diatoms; while desmids (more characteristic of oligotrophic waters) are scarce in both species and numbers. Oak Mere is peculiar in being almost wholly dominated by the green alga *Botryococcus braunii*. A similar contrast is observed in the case of zooplankton, which at Oak Mere is abundant but very restricted in species (Lind and Galliford 1952, Galliford 1954). The principal species, *Bosmina obtusirostris*, is a northern form typical of oligotrophic lakes, and has not been recorded from any other mere in

TABLE 1. *Ionic composition of some Cheshire meres, and of the average fresh water of the world*

	Total salts m.equiv/L	pH	Na	K	Ca	Mg	HCO ₃	Cl	SO ₄	NO ₃ -N	PO ₄ -P	SiO ₂
			m.equiv/L							ppm		
Sandiway	0.55	3.9	0.23	0.03	0.09	0.07	nil	0.28	0.27	0.07	0.001	1.0
Oak Mere	1.05	4.7	0.39	0.06	0.38	0.21	nil	0.50	0.54	0.05	0.02	1.4
Whitegate New Pool	3.14	7.8	0.54	0.08	1.70	0.82	1.51	0.71	0.92	0.06		
Hatch Mere	3.22	8.6	0.48	0.10	1.67	0.97	1.65	0.62	0.94	0.17		3.2
Budworth Pool	3.61	7.3	0.53	0.10	1.94	1.04	1.59	0.68	1.20	2.45	0.04	8.2
Rostherne Mere	4.28		0.62	0.11	2.60	0.98	2.00	0.68	1.50	0.53	0.11	1.3
Tatton Mere	4.48	7.8	0.88	0.12	2.34	1.15	2.39	0.87	1.21	0.02	0.05	
Pick Mere	6.01		0.89	0.12	3.35	1.66	2.93	0.96	2.09	0.08	0.07	2.6
Budworth Mere	6.99		1.30	0.16	3.65	1.88	3.10	1.30	2.51	0.57	0.29	2.6
Average of last seven (C)	4.53		0.75	0.11	2.46	1.21	2.17	0.83	1.48			
World average fresh water (W)	2.35		0.36	0.08	1.49	0.42	1.71	0.23	0.37	0.30	0.11	17.1
Ratio: C/W	1.9		2.1	1.4	1.7	2.9	1.3	3.6	4.0			

Cheshire. The shore vegetation at Sandiway and Oak Mere also lacks the reedswamp of *Phragmites* commonly fringing these meres. Concerning shore fauna, Dr. H. B. N. Hynes (private communication) describes Budworth Pool, Hatch, Rostherne, Pick, and Budworth Meres as rich, with plentiful *Gammarus*, *Asellus*, and (except at Pick Mere) molluscs. The fauna of Oak Mere is on the other hand sparse, and *Gammarus*, *Asellus*, and molluscs were not observed during his brief visit. Finally, it is stated by Boyd (1951) that the number of ducks and waders on Oak Mere is far fewer than on the other Cheshire meres, though the Common Gull often visits it in abundance.

METHODS

Surface waters were collected from the various meres during August 1954 (Tatton), October 1954 (Oak, Hatch, Pick, Rostherne, and Budworth Meres, and Budworth Pool), January 1955 (Sandiway), and October 1955 (Oak and Hatch Meres, Whitegate New Pool, and Budworth Pool). The samples were filtered through Whatman 541 filter papers, the first portion being discarded. Methods of analysis were those used by Gorham (1955); silica was estimated in the 1955 samples by the ammonium molybdate procedure, after reduction of the resultant yellow color to molybdenum blue.

RESULTS

The chemical data are presented in Table 1, in order of increasing total salt concentrations. The major ions are given as milliequivalents per litre, except for hydrogen ions, measured as pH. Dissolved nitrate, phosphate, and silica are shown as parts per million (ppm) of N, P and SiO₂. Since the differences between 1954 and 1955 samples from three meres were not of great importance, the data have been averaged. The average fresh water of the world (Conway 1942) is also represented in Table 1, and for comparative purposes the ratio of the normal Cheshire mere (average of last seven samples) to the world average is given in the final row.

Total salt concentration varies considerably in these waters. The lake at Sandiway is most dilute, with 0.55 m.equiv./L, while Oak Mere is about twice as concentrated. The other meres are extremely rich in salts, ranging from 3 to 7 m.equiv./L. Pick Mere and Budworth Mere, in the valley of the River Weaver, yielded the most concentrated waters.

Among the cations calcium is clearly dominant, except in the first two waters. Magnesium is next in importance, followed by sodium, which however preponderates strongly in the most dilute water from Sandiway. Potassium is by far the least plentiful of the four metal cations, as in

TABLE 2. *Ionic proportions in some Cheshire meres and other waters*

	Total salts m. equiv. /L	m. equiv. per cent of total cations or anions								
		H	Na	K	Ca	Mg	HCO ₃	Cl	SO ₄	
Lake District rain	0.17	26	52	3.1	9	10	nil	58	42	
Moor House blanket bog	0.38	32	40	1.9	12	13	nil	37	63	
Sandiway	0.55	24	42	5.5	16	13	nil	51	49	
Oak Mere	1.05	1	37	5.7	36	20	nil	48	51	
7 Cheshire meres	4.53	nil	17	2.4	54	27	48	18	33	
World average fresh water	2.35	nil	16	3.4	64	17	74	10	16	
Sunbiggin Tarn, on limestone	2.73	nil	7	0.4	85	8	86	6	8	

most fresh waters. Only the first two waters are acid, hydrogen ions being of considerable importance (0.13 m.equiv./L) in the Sandiway sample.

Of the major anions, bicarbonate is most abundant, except for Oak Mere and Sandiway where it is absent. In these waters sulphate and chloride are equally plentiful, while in the richer lakes sulphate is distinctly in excess of chloride.

The analyses for nitrate, phosphate, and silica were not made until some weeks after the samples had been collected and filtered, and so are not highly reliable. They show no relation to the concentrations of major ions, but this is not unusual. Nitrate and silica are highest in the heavily polluted Budworth Pool, the concentration of nitrate (2.5 ppm N) being especially remarkable. Nitrate is low (0.05 ppm N) in Oak Mere, where pollution is negligible; and also in Tatton Mere, the only water sampled in summer when nitrate is usually much reduced. Silica is lowest (1.0 ppm) in the Sandiway water. Dissolved phosphate is extremely high in Budworth Mere (0.29 ppm P), and in most samples this element is much more plentiful than in normal waters of the Lake District, an area of much harder rocks and less agricultural influence, where phosphate is usually very scarce (about 0.001–0.005 ppm P). Of the present series only Sandiway showed such a low phosphate concentration (0.001 ppm).

DISCUSSION

If the concentrations of major ions in Table 1 are recalculated to show their pro-

portional contributions to total cations and anions, certain features of interest become apparent. It is evident that the last seven meres resemble one another closely in their ionic proportions, and differ strikingly from Oak Mere, and especially from the Sandiway water. These differences are illustrated in Table 2, where the seven similar meres are represented by an average figure and compared with the other two, and with other types of water.

The Sandiway sample, with its high acidity, resembles waters from blanket bog at Moor House (Gorham 1956), whose proportions are also given in Table 2. These surface bog waters are quite unaffected by chemical influences from the mineral soil beneath, and depend entirely upon atmospheric precipitation for their mineral supply. However, they differ from the Sandiway water in being strongly colored by peaty organic material, and also having a rather higher proportion of sulphuric acid. Nevertheless, the degree of similarity strongly suggests that the Sandiway lake, small and without inflow or outflow, may be merely a rather impermeable gathering ground for rain water. (According to Mr. P. Hamer, a layer of compacted sand, known locally as "Foxes' Bench", occurs beneath the surface soil, and may be responsible for holding up the water level.) This impression is strengthened by comparison with Lake District rain (Gorham 1955), whose proportions are likewise shown in Table 2. The rain water resembles Sandiway even more closely than does the bog water, although only one-third as concentrated. It has not, of course, been subject to evaporation.

Oak Mere is clearly intermediate in its ionic proportions between Sandiway and the normal Cheshire mere. Acidity is low, but while the proportion of calcium has risen considerably above that of Sandiway, it is by no means up to that of the other meres, and bicarbonate is still lacking. It seems likely that Oak Mere is also fed mainly by surface runoff, and not by springs or ground water in intimate contact with rich mineral subsoil. On this view its water represents rain, modified by contact

with the surface soil over which it has flowed, but to a much lesser extent than in the other meres fed by ground water.

A point to be considered here is the fact that in 1951 the lake level (maximum depth 18 feet) was raised almost 2 feet by pumping from a nearby borehole. However, since the pH of the mere water is now just the same as before pumping took place (Lind and Galliford 1952—analyses of December 1948 and May 1951), marked residual effects would seem unlikely. The borehole water would almost certainly be rich in salts and therefore dense, and might be expected to sink to the bottom and seep away more rapidly than the incoming runoff.

The increased proportions of calcium and magnesium in Oak Mere as compared with Sandiway are presumably due to exchange of rain hydrogen ions (derived from atmospheric pollution by sulphuric acid, cf. Gorham 1955) for the divalent metal cations adsorbed in large amounts on soil colloids, though it is possible that some carbonates remain to be attacked in the horizons percolated by the runoff feeding the lake.

The assumption that Oak Mere is largely rain-fed is also strongly supported by what is known of its physiography and past history (see Lind 1952). It, like Sandiway, is a lake without inflow or outflow streams, lying on relatively high ground. It is however much larger (area 52 acres, maximum depth 18 feet), and so might be expected to receive water which has had longer and more intimate contact with mineral soil. Another feature of Oak Mere is the presence of a large peat deposit at one end, which through erosion has probably provided the impermeable basin seal retarding water loss through the sandy glacial drift beneath. The irregular fluctuations of level for which the lake has been known in the past may well be explained by partial breaching of this seal and its subsequent restoration. For example, there was a long-continued decline between 1934 and the winter of 1950–1, when the level was restored by heavy snow and rain, and continued high through the ensuing summer. It is reasonable to suppose that the abnormal floods carried in sufficient peat and silt to bring

back the basin seal to its former efficiency. The presence of such a seal is further attested by the phenomena observed when two aerial bombs dropped on the lake bank in 1941, and a flow of water past the bottoms of the craters and away from the lake created appreciable suction (Lind 1951).

In considering the normal Cheshire meres, exemplified by the last seven in Table 1, it may be noted that the two richest in salts, Pick and Budworth Meres, while occupying low land in the vicinity of the Northwich salt mines, exhibit ionic proportions very similar to those of the others. That is to say, they are rich in calcium bicarbonate, and show no sign of brine infiltration from the salt beds. Nevertheless, while the normal meres are strongly calcareous, the high proportions of sodium chloride, and especially of magnesium sulphate, mark them off from lakes owing their high ionic concentrations solely to their situation in limestone country. One of these, Sunbiggin Tarn in the Lake District, which closely resembles the limestone lakes of the Siljan district in Sweden (Lohammar 1938), is represented in Table 2.

The Cheshire waters are of course much richer in all major ions than the normal non-calcareous Lake District waters (Mackereth 1957). These lie on much harder and less easily weathered substrata, and in an area with not only a great excess of rainfall over evaporation, but also strong relief, both factors favouring rapid transport of salts to the sea and low ionic concentrations in the lake waters.

A comparison of the Cheshire meres with the average fresh water of the world (see Tables 1 and 2) shows the former to be about twice as concentrated, and enriched especially in chloride and sulphate, to a lesser extent in magnesium. There is also a striking difference in the balance of sodium and chloride. In the Cheshire series the two are almost equivalent, pointing to a marine origin; whereas in the world average water the proportion of sodium is distinctly greater than that of chloride, the excess no doubt originating in rock-weathering of aluminosilicate minerals.

Examination of the ratios of sodium to

chloride in the individual mere waters raises further points of interest. The Sandiway ratio, 0.82, is close to that of sea water, 0.85, and hence probably close to the average ratio in rain. (The Lake District rain ratio is in fact 0.90, but being a spring-autumn value may be a little high due to dust supply of sodium; unpublished winter analyses show an opposite and compensatory tendency toward a ratio lower than in sea water, owing probably to atmospheric pollution by industrial hydrochloric acid.) Oak Mere, Whitegate New Pool, Hatch Mere, and Budworth Pool show a decline to between 0.76 and 0.78, which may perhaps result from an exchange of sodium, abundant in rain, for the divalent metal cations adsorbed in large quantities on soil colloids. In contrast, the four most concentrated waters (Rostherne, Tatton, Pick, and Budworth Meres) show distinctly higher ratios, varying from 0.91 to 1.01. These meres all lie more in the lowland than the first group, which is located near the edge of the Delamere Forest upland. Thus the relatively high sodium/chloride ratios may still reflect some slight contribution of sodium (probably adsorbed on soil colloids) from either the former salt lakes or the later marine submergence of this district. The high total salt concentrations of the above four meres are also presumably connected with their more low-lying situation.

The richness of the Cheshire waters in salts other than calcium bicarbonate reflects the conditions in which the geological substratum underlying the meres was laid down. During the Triassic period when the Keuper marls were deposited the climate was extremely arid, and the Cheshire plain was, as now, very flat (Edmunds and Oakley 1947). Whereas under high rainfall most of the more mobile ions such as chloride and sulphate would be leached away and replaced by bicarbonate, excessive evaporation and impeded drainage at this time combined to produce highly saline soils in the lowlands, with the formation of salt lakes in the lowest-lying basins, as for example around Northwich. The concentration of salts by evaporation led at the same time to precipi-

tation of calcium carbonate in the Keuper marl beds, which however are not highly calcareous but made up largely of clays mixed with quartz dust of wind-blown desert origin, and of tiny crystals of dolomite. Later, in Jurassic times, there was a long period of marine submergence. Under the much moister climatic conditions of more recent periods, most of the saline residues have been washed out of the surface layers of the Keuper deposits, and at present weathering of calcium carbonate in the marls presumably provides the major source of ions for the ground waters feeding the meres.

However, in sites like Oak Mere, and especially Sandiway, where local irregularities of upland topography seal off a basin from ground water supply and leave it largely dependent upon runoff, the supply of calcium bicarbonate is greatly reduced, since only the uppermost horizons of soil, subject to the maximum degree of leaching, are percolated by the inflowing rainfall. It is no doubt this physiographic situation which is primarily responsible for the biological peculiarities of Oak Mere, so different in character from the other meres of the Cheshire plain.

A last point to be remarked is the comparative poverty of the Cheshire waters in silica as compared with the world average water. The Cheshire average of about 4 ppm SiO_2 is roughly comparable with levels in the much more dilute Lake District waters. A likely explanation is that in the Cheshire district leaching has not progressed to an advanced stage, and only the more mobile elements are being removed in quantity. Although much of the chloride and sulphate has gone from the surface soils, and bicarbonates are now accompanying the metal cations on their way seaward, the aluminosilicates have probably not yet suffered severe attack.

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The Metabolism of Radionuclides by Marine Organisms. III. The Uptake of Calcium⁴⁵ in Solution by Marine Fish^{1,2}

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ABSTRACT

To determine whether marine fish required calcium in their diet, or whether they could take up an adequate amount from sea water, non-feeding fish (*Tilapia mossambica*) were put in artificial sea water with calcium⁴⁵. The uptake was rapid at first, then continued at a slow rate for the duration of the experiment (21 days). The normal concentration ratio of calcium by marine fish is about 20. At 21 days, the ratio of Ca⁴⁵ in the fish to the Ca⁴⁵ in an equal weight of sea water was about 0.6. The readily exchangeable calcium in the fish is therefore only a few per cent of the total. The concentration ratio of 0.6 would seem to preclude the necessity of feeding captive marine fish calcium in order to have an adequate diet. The skeleton contained about 43 per cent of the accumulated Ca⁴⁵, the integument 24 per cent, the viscera 21 per cent, the gills 8 per cent, and the muscle 4 per cent. The Sr/Ca ratio in marine fish as a whole is about 1:400, but the ratio in normal sea water is about 1:40. This means that marine fish discriminate against strontium either by excreting it faster or by absorbing it less.

During some studies on the metabolism of radiostrontium by marine fishes (Boroughs, Townsley, and Hiatt 1956) it occurred to us that our results may have been influenced to some extent by feeding captive fish an artificial diet which may have been deficient in both calcium and strontium. Although marine fish live in an environment rich in both calcium and strontium, no published information could be found concerning the availability of these elements to fishes directly from the sea water. Because freshwater fishes, such as brook trout and guppies, can accumulate calcium directly from their environment (Lovelace and Podoliak 1952, Rosenthal 1956), we designed a simple experiment to test the hypothesis that marine fish can take up and accumulate calcium from sea water.

MATERIALS AND METHODS

Artificial sea water was made up according to Lyman and Fleming (1940). The total calcium was adjusted so that the low specific activity Ca⁴⁵ which was obtained from Oak Ridge plus the added calcium

were just equal to the calcium of sea water. *Tilapia mossambica*, the fish used for these experiments, were kept in carboys containing 946 microcuries of Ca⁴⁵ in 20 liters of water. The water temperature was about 22°C throughout the experiment. The extremes were 20.5° and 23.2°C. The water was aerated, but the fish were not fed during the entire experiment. Six fish were kept in each carboy and three fish were removed at each time interval from four hours to 21 days. The fish were then dissected, ashed, and counted according to the procedure described elsewhere (Boroughs, Townsley, and Hiatt 1956). An aliquot of the dose was counted to correct for decay, and appropriate corrections were made for self-absorption.

RESULTS AND DISCUSSION

Figure 1 shows that *Tilapia*, a sluggish fish, took up the calcium from solution rather rapidly, and that the uptake continued throughout the duration of the experiment. Although the three fish in the three-day carboy were very small in comparison with the other fish used (average weight: 72 g, while the average of all the fish was 102 g), size alone cannot account for the dip in the curve. The same data were plotted in Figure 2 in order to allow for the weight of each

¹ This work was carried out by means of Contract No. AT(04-3)-56 between the U. S. Atomic Energy Commission and the University of Hawaii.

² Contribution No. 84, Hawaii Marine Laboratory, University of Hawaii.

fish, and the dip still occurs. A measurement of the radioactivity present in the carboy at the beginning of the experiment showed that this carboy received about 20

per cent less Ca^{45} than did the other carboys. At any rate, we attribute no biological significance to the dip at three days.

Figure 2 also indicates that the concentration ratio achieved during the 21 days is about 0.6. The concentration ratio is here defined as the microcuries/g fresh weight of fish divided by the microcuries/g of sea water. In other words, the internal concentration of calcium had not reached the external concentration.

Figure 3 shows amounts of Ca^{45} recovered in five different organ-systems of *Tilapia*. As one would expect, most of the radioactivity appeared in the skeleton. At 21 days, 43 per cent of the Ca^{45} was in the skeleton, 24 per cent in the integument, 21 per cent in the viscera, 8 per cent in the gills, and 4 per cent in the muscle. This distribution does not correspond to the distribution of non-radioactive calcium in these tissues. On the basis of an elemental analysis of tuna fish by Goldberg (unpublished), and an analysis of the percentage of the total ash contributed by each organ of tuna fish made in this laboratory (Boroughs, Townsley, and Hiatt 1956) it is apparent that about 70 per



FIG. 1. The rate of uptake of calcium⁴⁵ from solution by *Tilapia mossambica*.

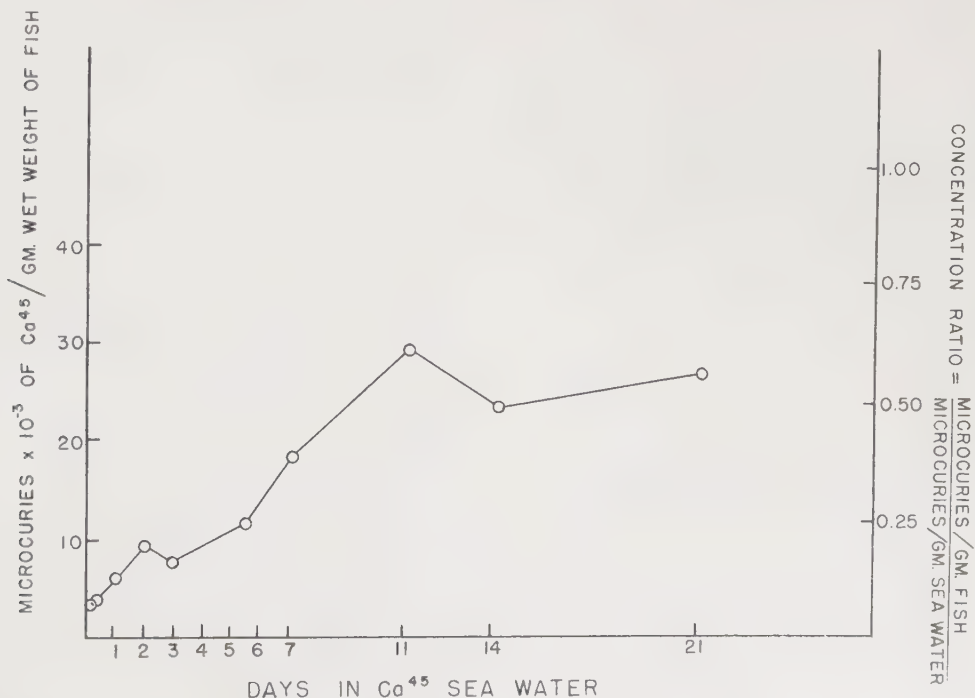


FIG. 2. The rate of uptake of calcium⁴⁵ from solution by *Tilapia mossambica* expressed as the concentration ratio.

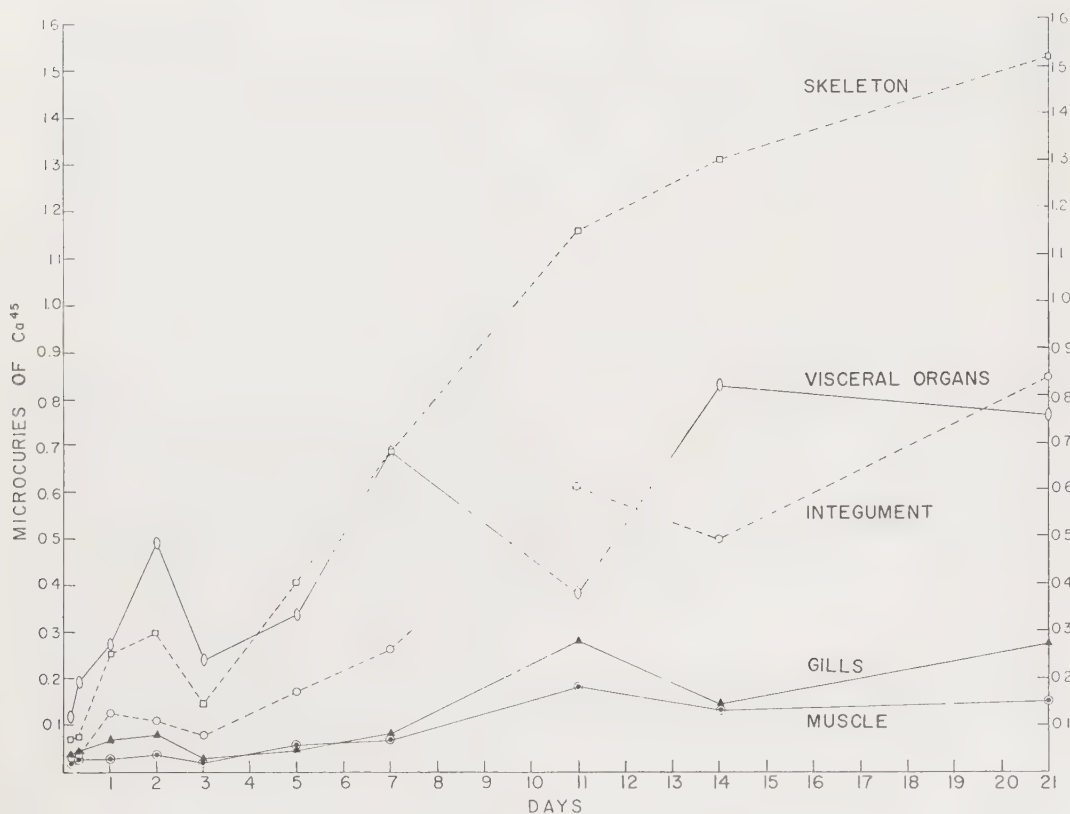


FIG. 3. The internal distribution of calcium⁴⁵ taken up by *Tilapia mossambica* from solution.

cent of the total calcium is in the bones, 15 per cent in the gills, 6 per cent in the integument, 3 per cent in the viscera, including the blood, and 1–2 per cent in the muscle.

We have no data on the calcium content of *Tilapia*, but Goldberg's analysis of the anchoveta, a small fish roughly comparable to *Tilapia* in form, indicates that the calcium content is approximately the same in anchovetas and tuna. The calcium content of *Tilapia* is not likely to be very different from these other fish, and one may infer, therefore, that continued exposure to radiocalcium would result in the continued accretion of this element in the bones and gills, but a comparative loss in the integument, viscera, and muscles.

It is interesting to note that a similar experiment on the uptake of radiostrontium in solution by the same species of fish (Boroughs, Townsley, and Hiatt 1956) indicates that the concentration ratio reached in 21

days was only about half of that reached with radiocalcium even though the concentration of radioactive strontium atoms was about twice that of the radioactive calcium atoms. A summary of several experiments on the comparative metabolism of these two elements in various mammals (Norris and Kisielski 1948) shows that in both the rat and mouse, and by either oral or intravenous administration, the percentage retention of strontium is about half that of calcium. Pecher (1941) found that the intravenous injection in mice of 0.8 mg of Ca as lactate resulted in the retention of 58 per cent of the dose within 24 hours. The injection of 1.6 mg of Sr as lactate, however, resulted in only 33 per cent retention. Results such as these are difficult to understand.

The authors are aware of no Sr/Ca ratio of 1:2 in any organ of those marine fish whose elemental composition has been reported. If both elements were accumulated

on an equimolar basis, the percentage of strontium in the ash of the organ or organism would be about twice that of calcium, because this is approximately the ratio of their atomic weights. One finds, on the contrary, that the ratio of strontium to calcium in marine fish is of the order 1:400 or less. This means that for each mole of Sr there are approximately 800 moles of Ca. If these same ratios of Sr/Ca obtain in mammals, one might be tempted to ascribe the 1:2 ratio actually found for radiostrontium and radiocalcium to a transient state. In the mammal it is conceivable that a surge of strontium not ordinarily present in the diet might give rise to very high transient ratios. In marine fish, however, such a situation would not be possible unless the fish were dosed with strontium far in excess of the concentrations used in our experiments. These concentrations were in each instance below the concentration of strontium in sea water. The Sr/Ca ratio in sea water is about 1:40 or 5:200. This means that fish discriminate against strontium, in comparison with calcium, either by excreting it faster, or by absorbing it less. The same discrimination against strontium occurs in other animals and in plants as well (Libby 1956; MacDonald, Noyes, and Lorick 1956). This discrimination, coupled with the large concentration of calcium and the relatively large concentration of strontium in sea water, is a fortunate combination which reduces the radiation hazard of this important fission product to some marine organisms and to man as well.

According to various analyses of the calcium content of marine fishes (Vinogradov 1953) there is approximately 20 times as much calcium in a whole fish as there is in an equal weight of sea water. The concentration ratio is therefore 20. This amount of course is quite variable, and depends for the most part upon the age and species of fish. Assuming a concentration ratio of between 0.5 and 0.7 for the 21 day fish, it is evident that only 2-3 per cent of the total calcium in the body is readily exchangeable under the conditions of the experiment. In general, it is considered that the turnover

time for bone calcium is very long. Once the calcium is incorporated into some sort of matrix, only a small amount is involved in metabolism under normal conditions, and most of it remains *in situ* for the duration of the animal's life.

The rapid uptake of both calcium and strontium by marine fish, the continuous uptake over at least a 21-day period, and the noteworthy concentration ratio for strontium and calcium of about 1:2 indicate strongly that the artificial diet fed captive tuna during experiments on the uptake, accumulation, and loss of radiostrontium would have had little effect or no effect on the results of the experiments.

SUMMARY

Tilapia mossambica, sluggish marine or brackish water fish, were put in artificial sea water with calcium⁴⁵ so that the total calcium concentration was equal to that of sea water. The fish were not fed during the experiment which lasted 21 days. During this time, the fish as a whole took up the Ca⁴⁵ to the extent of about 60 per cent of the Ca⁴⁵ concentration in the water. Most of the radioactivity was recovered in the skeleton and integument, but the values obtained do not correspond to the elemental analysis of various fish for calcium. Only a few per cent of the body calcium is apparently readily exchangeable. It is concluded that marine fishes can take up calcium directly from sea water, and do not need a dietary source for this element. In comparison with a similar experiment using radiostrontium, it is further concluded that marine fishes discriminate against strontium in favor of calcium.

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The Effect of Copper on the Growth of Bacteria Isolated from Marine Environments

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ABSTRACT

The use of copper may prove feasible for the control of catastrophic fish mortalities associated with blooms of *Gymnodinium brevis*. Prerequisite is knowledge of the effect that relatively high concentrations of copper may have on the marine community as a whole. In this study the effect of copper on the growth of 145 marine bacteria was measured. All of the bacteria grew in a medium containing copper in concentrations up to 0.25 mg/L. This concentration was compared to the *in vivo* (0.2 mg/L) and *in vitro* (0.1 mg/L) lethal dose of copper for *G. brevis*. In addition, the growth of approximately 4 per cent of the bacteria was stimulated by this concentration of copper.

INTRODUCTION

During the latter part of 1955, red tide outbreaks associated with *Gymnodinium brevis* were reported along the Gulf coast of Mexico and along the southeast coast of Texas (Wilson and Ray 1956). These blooms were accompanied by extensive kills involving millions of pounds of commercial and game fish, paralleling the destructiveness of Florida's 1946 outbreak (Gunter *et al.* 1948, Galtsoff 1948). In all of these instances *G. brevis* (Davis 1948) was identified and found in large numbers. Other red tide outbreaks have been reported (Feinstein *et al.* 1955, Lackey and Hynes 1955).

Recently *G. brevis* was isolated and is being maintained in pure culture. Results of laboratory experiments by Dr. S. Ray and Mr. W. Wilson¹ with unialgal and pure cultures demonstrated that concentrations of *G. brevis* comparable to those of the Florida red tide were toxic to fish.

This paper reports on one aspect of a major project concerning red tide control measures presently in progress by the Gulf Fishery Investigations of the U. S. Fish and Wildlife Service. The study was prompted by the proposal that treatment of possible foci of infection with heavy metals may prove practical for the control of catastro-

phic blooms of *G. brevis*. Prior to large-scale field operations, it was decided to investigate the possibility of adverse effects of heavy metals on organisms other than *G. brevis*. Copper was selected because initial studies by Mr. Wilson showed that *G. brevis* is extremely sensitive to concentrations of copper only slightly above those normally present in regions along the west Florida coast (Mr. J. Bell¹).

Copper has been used extensively for the control of algal blooms. Whipple (1948) cited Kellerman who studied the effect of copper sulfate upon fresh-water fish. It was shown that concentrations used for the destruction of microscopic organisms were close to the doses that would kill fish. A list was compiled by Chow and Thompson (1952) of the copper content of sea water found by various investigators in a variety of localities. Riley (1937) found a range of 0.001–0.015 mg/L off the mouth of the Mississippi River. At one of his stations a range of 0.02–0.025 mg/L was found. Atkins (1953) reported a seasonal variation of copper in surface waters of the English Channel ranging from 0.0015 mg/L in early autumn to 0.025 mg/L in winter. Higher values for Long Island Sound (Prytherch 1934, Galtsoff 1943) were attributed by Chow and Thompson (1954) to discharges of industrial wastes.

The effect of copper on various organisms involved in marine fouling has been re-

¹ We should like to thank Dr. S. Ray and Mr. W. Wilson of this laboratory and Mr. J. Bell of our field station in Naples, Florida, for making this information available prior to publication.

viewed (Woods Hole Oceanogr. Inst. 1952). Harvey (1955) stated that the concentration of cupric ion which is poisonous to marine plants and animals was approximately 1.0 mg/L. However, the effective algicidal dose of copper sulfate *in vivo* is dependent on the chemical and physical properties of the water to which it is added. Soluble and insoluble components will effectively chelate copper and hence decrease its effectiveness. Harvey (1955) stated that when added to sea water ethylene-diamine-tetra-acetate would reduce the poisonous effect of copper on algae. In experiments with unialgal cultures of *G. brevis*, Mr. Wilson found that EDTA reduced the toxic effect of otherwise lethal doses of copper.

This study reports on the effect of copper on the growth of bacteria which were isolated from marine samples. The physiological and biochemical properties of the isolates and the effect of heavy metals on such activities will be the subject of another paper.

METHODS AND MATERIALS

Bacteria were isolated from mud and water samples (Table 1) taken from a lagoon (Lagoon 2 and 3), from mullet (*Mugil* sp.) intestinal contents (Mullet a, b, and c), from the slime of an eel (*Mystriophis* sp.), from laboratory tanks of unialgal cultures of *G. brevis* (Tank B₁ and B₅), and from the southeast coast of Texas during a *G. brevis* bloom (Tex. Red Tide). Other cultures (Florida) were obtained from the collection of Dr. S. Ray. Most of Dr. Ray's cultures were iso-

lated from samples taken along the west coast of Florida.

Samples were plated by the dilution plate count technique or streaked directly onto Medium A of the following composition: trypticase, peptone, and yeast extract, 0.005 per cent each; sodium acetate, 0.01 per cent; Bacto agar, 1.2 per cent; and made to volume with aged Gulf water collected 50 miles off the southwest coast of Florida. The final pH of the medium was 7.4–7.8 after autoclaving at 121°C for 15 min. Plates were incubated for 2–15 days at 20–25°C.

Isolated colonies were picked and restreaked several times to ensure culture purity. Stock cultures were maintained at 20–25°C in screw-cap tubes on the following medium: trypticase, peptone, yeast extract, 0.0075 per cent each; sodium acetate, 0.01 per cent; Bacto agar, 0.2 per cent; and made to volume with aged Gulf water.

Bacterial types were tentatively determined according to the following criteria: nitrate reduction, degradation of chitin and cellulose, catalase reaction, liquefaction of gelatin, anaerobic growth, growth patterns, temperature range, Gram stain, phase-microscopic morphology and motility, and source of isolation. Only those isolates which differed from one another in one or more of these characteristics are reported here. Thus each culture represented a major morphological and physiological category or a distinct variant. No attempt was made to assign generic or specific names to the organisms.

The effect of $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ on growth of the bacteria was tested in Medium A minus the agar. Copper sulfate was added to give the following final concentrations of copper: 0.0, 0.25, 1.3, 3.1, 7.6, 12.7, 20.4, 25.4, 35.6, and 50.9 mg/L. The pH of each batch of medium was adjusted with 1 N NaOH to pH 7.4–7.6. This was necessary because the addition of the larger amounts of copper lowered the pH considerably. Media were tubed in 5 ml quantities in screw-cap test tubes and autoclaved at 121°C for 15 min.

Inoculum was prepared by diluting one drop of a 24–48 hr culture, grown in Medium A minus the agar, in 5 ml of the same

TABLE 1. Source and numbers of bacterial cultures which would grow in and below the concentration of copper indicated

Source of culture	Cu, mg/L									
	0	0.25	1.3	3.1	7.6	12.7	20.4	25.4	35.6	50.9
Mullet a.....					1		1	2	2	
Mullet b.....					1	1		1	3	4
Mullet c.....					3	1	5	3	5	4
Lagoon 2.....		1	1	2	1	4	5		1	
Lagoon 3.....				7	7	9	1	5	3	8
Florida.....				1	1	5	2	5	2	3
Texas Red Tide.....						2		1		
Eel.....						1	1			
Tank B ₁				1		1		3		
Tank B ₅		1		2	2	3	1	3	6	6

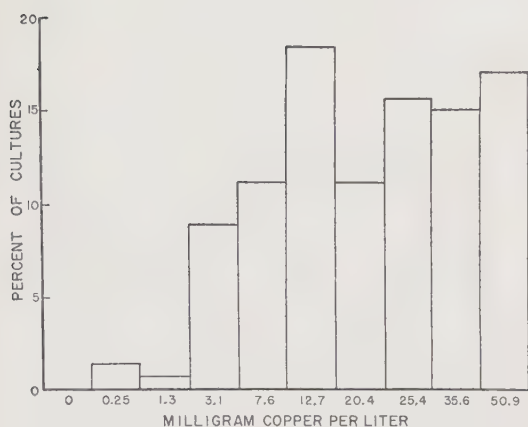


FIG. 1. Per cent of cultures that showed minimal growth in concentration of copper indicated.

medium. One drop of this suspension was used per tube.

Cultures were incubated at 24°C for 4 days unless otherwise indicated. Growth was measured turbidimetrically with a Klett-Summerson colorimeter using a number 42 filter.

RESULTS

The effect of copper on the growth of 145 cultures is given in Table 1. The source of each isolate and the number of cultures which grew in the presence of and below the indicated concentrations of copper are shown. Medium A minus the agar supported growth of all the cultures. Except for 3 cultures which required 8 days' incubation, turbidimetric measurements were recorded after 4 days. These 3 slow-growing cultures were sensitive to copper concentrations exceeding 1.3 mg/L, whereas the remainder grew within a range of 3.1–50.9 mg/L. Twenty-five grew in the highest concentrations of copper used. As shown in Figure 1, the frequency of occurrence of cultures tolerant to copper increased with increasing concentrations of copper.

Typical growth responses of the cultures to increasing concentrations of copper are shown in Figure 2. Curve A represented 79 per cent of the cultures. The slope ranged from a maximum for those cultures which were inhibited by the lower copper concentrations to a minimum for those cultures which were relatively unaffected by

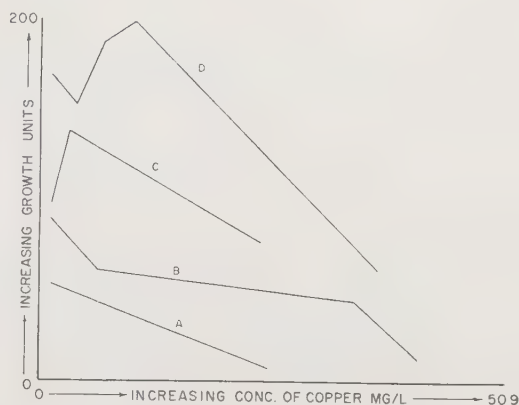


FIG. 2. Typical growth responses of cultures to increasing copper concentrations.

the higher quantities. One culture grew equally well at all copper concentrations. Curve B was representative of 7 per cent of the cultures. The predominant growth characteristics were a slight inhibition at low copper concentrations, followed by a plateau, and then an inhibition at high copper concentrations. Curve C represented 4 per cent of the cultures. The growth of members of this group was stimulated by small additions of copper. Curve D is representative of 10 per cent of the cultures. The supposedly stimulatory effect at the lower copper levels was attributed to increased pigment production.

DISCUSSION

The use of copper may be practical for the control of catastrophic fish mortalities associated with blooms of *G. brevis*. This type of control requires some knowledge of the effect that relatively high concentrations of copper may have on the marine community as a whole.

In these experiments concentrations of copper up to 0.25 mg/L did not inhibit the initial growth of any of the bacteria that were tested. Except for 3 normally slow-growing cultures, all of them grew in the presence of 3.1 mg/L. Mr. Wilson demonstrated that *G. brevis* is killed by 0.05–0.1 mg/L. The addition of 7.6 mg/L allowed the growth of 89 per cent of the isolates; 12.7 mg/L allowed growth of 78 per cent.

Provided that the bacteria tested are representative of areas susceptible to *G. brevis*

blooms, the concentration of copper could be effectively increased to 0.25 mg/L without bactericidal effects. Harvey (1955) estimated that the concentration of cupric ion which is toxic to marine plants and animals was approximately 1.0 mg/L. This concentration is approximately 10 times higher than the lethal dose for *G. brevis* in laboratory experiments and 5 times the minimum lethal dose (MLD) established by Mr. Bell in red tide areas along the west coast of Florida. At copper concentrations of 1.3 mg/L, approximately 1.4 per cent of the bacteria screened did not grow. Waksman *et al.* (1943) reported that concentrations of copper up to 10 mg/L did not affect the number of bacteria found in water taken near the dock of the Oceanographic Institution at Woods Hole. Thus, it appears that an *in vivo* MLD of 1.3 mg/L would not materially affect the growth of bacterial populations. In addition, this concentration of copper stimulated the growth of 4 per cent of the cultures as shown in Figure 2, Curve C.

SUMMARY

Bacteria were isolated from a number of marine samples. On the basis of differential morphological and physiological properties, 145 different cultures were selected and the effect of increasing copper concentrations on their growth was measured.

Growth patterns of the cultures as affected by copper were divided into four representative groups which are described.

All of the cultures grew in a basal medium containing a copper concentration of 0.25 mg/L. Seventeen per cent tolerated up to 50.9 mg/L which was the highest concentration of copper tested. These values were compared with the *in vitro* lethal concentration (0.1 mg/L) for *Gymnodinium brevis* and the estimated minimum lethal dose (MLD) *in vivo* (0.2 mg/L). At the MLD level, all of the bacteria grew and the growth of approximately 4 per cent was stimulated.

Considering that the bacteria tested were representative of areas susceptible to *G. brevis* blooms, an *in vivo* MLD of 1.3 mg/L would not materially interfere with the

growth of these bacteria and may be beneficial to some.

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Evidence for a Photosynthetic Daily Periodicity¹

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ABSTRACT

It appears that there is a variation of around 5.7-fold in the ability of oceanic phytoplankton to photosynthetically fix carbon depending upon the time of day the productivity of fixed carbon is determined. The maximum photosynthetic ability appears to be during the few hours before mid-day, and the minimum ability around 1900 hours as determined by the carbon¹⁴ "light-dark bottle" technique. The original determinations were made in surface waters at surface temperature on three crossings of the equatorial region between about 110 and 140 degrees West Longitude.

INTRODUCTION

In analyzing net photosynthetic carbon fixation productivity data from eastern tropical Pacific surface waters an interesting phenomenon has come to light: a variation in net productivity of about 5.7-fold depending upon the time of day the sampling is done (see Fig. 1). The sampling, which is the basis for this pronouncement, was done for the most part at about 0800 and 1900 hours each day on three sections across the equator at approximately 110, 120, and 140 degrees West Longitude. The particular data illustrated in Figure 1 were collected while the vessel cruised from 7 degrees North Latitude to 8 degrees South Latitude at about 110 degrees West Longitude. This consistent variation may be indicative of a phenomenon of which we were not previously aware—a daily physiological rhythm in photosynthesizing ability.

Productivity was determined by the quantitative carbon¹⁴ tracer method. Details of

the method, basically that of Steemann-Nielsen (1952), may, for the present, be obtained from the senior author in mimeographed form. In brief, carbon¹⁴ of a known specific activity was added as a sodium carbonate solution to illuminated bottles (light bottles) and to non-illuminated (dark) bottles of water. After a period (usually 4 to 6 hours) of incubation under uniform conditions of light (at about 1500 foot-candles), or darkness, at sea surface temperature the difference in radioactivity between the *dark*- and *light*-bottle residues, filtered out on filters retaining all particles over 0.8 microns in diameter, was determined. Taking into account the specific activities and volumes concerned we calculated fixation rates in milligrams of carbon fixed per hour per cubic meter of water. This we consider, here, to be the net productivity for the surface waters involved. We do not pretend net productivity is the real *in vivo* productivity, but we feel that the two are closely related. The complete set of raw data may be obtained from the authors in mimeographed form, although it is expected to appear soon in a Special Scientific Report of the U. S. Fish and Wildlife Service.

¹ This work was supported by the research contract AT(04-3)15 of the U. S. Atomic Energy Commission and by Faculty Research Committee Funds of the University of Hawaii. The field manipulations were done aboard the U. S. Fish & Wildlife Service vessel *Hugh M. Smith* during the EASTROPIC cruise (Cruise 31) in October and November of 1955, and another cruise (Cruise 33) of the same vessel in March 1956. We wish to express our appreciation to the administration of the U. S. Fish & Wildlife Service's Pacific Oceanic Fishery Investigations for permitting Messrs. Robert M. Pyle and Mikihiro Oguri to accompany these cruises and make the field observations upon which this work is based.

A relationship between morning (0800) and evening (1900) productivity figures was determined as a correction factor that could be used in adjusting the raw data taken at different times of day so that the horizontal aspects of productivity could be plotted. To do this the data were separated into three groups depending upon the approxi-

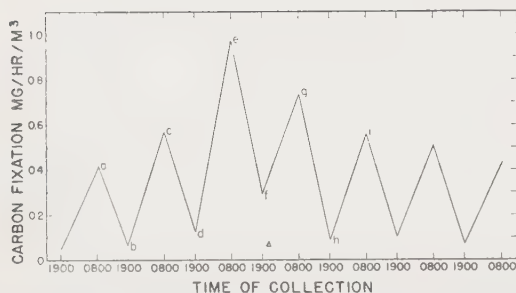


FIG. 1. Morning-evening variation in photosynthesizing ability. The equator was crossed at the time indicated by the small black delta above the time axis. Each point represents the results averaged from two light bottles and two dark bottles. The samples were collected successively toward the right side of the figure.

mate longitude of the equatorial crossing on which they were obtained. For variance analysis, to counteract the effects of sailing direction and variation with latitude, we treated the data (Fig. 1) as overlapping pairs of values; a/b, c/b, c/d, e/d, e/f, etc. In these groups the denominator represents the following or preceding evening fixation rate value, and the numerator the related morning fixation rate value. The deviation of these fractions from the mean was determined. Table 1 presents a summary of the information obtained from these three lots of data. The 120-degree section included the crossing of a sharp front (Cromwell & Reid 1956). This may explain the large deviation in the ratio between pairs in this particular group. The equatorial water mass at 140 degrees West Longitude is comparatively consistent in its structure, and that near 110 or 120 degrees is more variable. The mean relationship between the morning/

TABLE 1. Results of a statistical examination of the relationship between the 0800 and 1900 productivity data

	Group I 110° W. Long.	Group II 120° W. Long.	Group III 140° W. Long.
Ratio: 0800 productivity 1900 productivity	6.1	5.4	5.4
No. pairs	13	11	7
Standard deviation	1.9	3.4	1.3 [*]

* One figure (2 pairs) was excluded, which when included raised the standard deviation to 19.1 and the arithmetic mean to 14.7.

evening fixations obtained by weighting for the size of the three different groups is 5.69.

The results obtained on *Smith* cruise 31 indicated moderately high productivity rates at about 0400, the highest rates during the late morning daylight hours, somewhat lower photosynthesis in the afternoon with a sharp drop toward 1900, with higher intermediate values being obtained between 1900 and midnight. We suspected some cause in the shipboard routine for this asymmetric variation with time of day but we did not discover any. Unfortunately, few samples were taken on the cruise at times other than 0800 or 1900.

We recalled *a posteriori* the frequently reported observation of the rhythmic onset of reproductive activities with the onset of evening and the termination of these and the onset of feeding or vegetative activities with the onset of daylight. In the review of periodicity by Friesner (1920) such phenomena are, for example, reported at the cellular level in higher plants, where there may be several periods per day, and in algae. The senior author has rather uncritically noted on occasion the onset of reproduction in various crude cultures of cryptomonads and other marine unicellular phytoflagellates in the evening with completion of reproductive activity early in the morning. The migration of pigments in the eyes of crustaceans (see review by Kleinholz 1942) is to be mentioned as a daily physiological rhythm of a different sort. At the cellular level of organization Zeuthen (1950) has shown for young embryos that as karyokinesis sets in there is an increase in oxygen consumption and a related decrease terminating in cytokinesis. Daily and monthly variations have been noted (Brown *et al.* 1955a and 1955b) in the oxygen uptake of whole organisms. In this case carrots and potatoes showed minimal oxygen consumption between 1700 and 1900 daily especially at times of new moon. This all points to the generality of daily (or more frequent) physiological rhythms affecting at least respiration in various organisms.

Our information leads us to the hypothesis that such daily rhythms extend to photosynthesis. Having been unable to locate

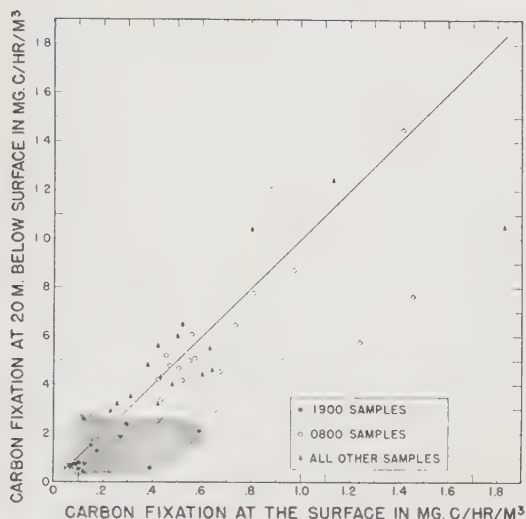


FIG. 2. Productivity at the surface in comparison to that 20 meters below the surface. The samples collected at 1900 are included within the hatched area.

any previous record of such a periodicity² our first inclination was to consider the hypothesis that the variations seen could be explained on the basis of plankton migration. The phytoplankton, surely for the most part near 5 microns in diameter, could hardly be expected to migrate to below 20 meters sufficiently quickly to cause the observed very similar fixations obtained (Fig. 2) from the surface and 20-meter samples throughout the day. Zooplankton migrating upward at dark is an alternative hypothesis.

To test the hypothesis that there is a daily rhythm in the photosynthesizing ability of the phytoplankton encountered in the Central Pacific and possibly to enable us to eliminate the alternative hypotheses given above, a series of tests was devised. In brief this test series consisted of determining the photosynthesizing ability of the organ-

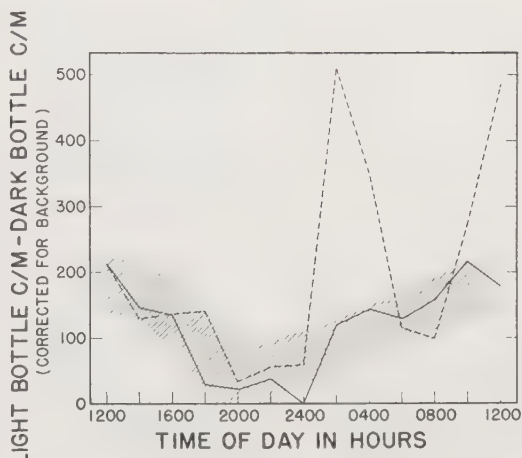


FIG. 3. Photosynthetic ability of samples collected at two-hour intervals from over the side of the cruising vessel (broken line) and from a carboy lashed on deck (solid line) plotted as a function of the time of sampling.

isms collected every two hours from the surface waters of the sea over a 24-hour period. At the same time a similar series of determinations was made from aliquots drawn from a carboy of water taken from the sea surface at the beginning of the experimental 24-hour period. We felt the carboy part of the experiment would offset the geographic variations met in the surface as the ship cruised and would at the same time check on the migration hypotheses. The surface sampling from the sea we felt would provide us with an idea of the nature of the variation with time *in vivo* (since from our fragmentary information obtained on *Smith* Cruise 31 we did not expect the curve to be symmetrical) and also offset to a certain extent what we expected in the way of so-called bottle effects.

The run (Fig. 3) completed on *Smith* Cruise 33 and the data obtained from other experiments all yielded similar variations. There was a variation of about 7- or 8-fold in the productivity of fixed carbon between the 0800 sampling and that at 1900. In this one 24-hour run a maximum 12-fold variation was obtained. Similar results were obtained both in the series of surface samples and in the series where sampling was done from a carboy on deck at three different times widely spaced geographically

² Since writing this our attention has been drawn to a symposium report by A. Pirson of such variation in *Hydrodictyon*. Various of our correspondents feel these periodicities may be due to variations in cellular chlorophyll content. Our studies at sea in the Pacific have revealed no relationship between chlorophyll content of the waters and carbon fixation. One brief study at the Woods Hole Oceanographic Institute done by John Ryther, Charles Yentsch, and the junior author revealed some degree of covariance.

and chronologically, and utilizing to a large extent different apparatus and personnel. With but few complete runs on the experiment we can only say that the maximum rates have been obtained generally in the late morning daylight hours and the minimum rates just at dark in the evening.

DISCUSSION

These repeatedly-found variations in time and magnitude of photosynthesizing potential lead us to discount the two migration hypotheses and to consider as a theory tenable for further testing the hypothesis that there is a daily periodicity in photosynthesizing ability with variations in the photosynthetic potential to be expected illustrated by the hatched area in Figure 3. Furthermore this is an effect that persists for a period of at least a few hours under the uniform artificial conditions of our method.

It may be that further testing of this theory should be along lines designed to take into account respiratory rhythms, for a large increase in respiratory rate could appear as a nullification of photosynthesis as could also variations in chlorophyll content. Ryther (1956) has shown that in some cases photosynthesis in phytoplankton may be only 1.4 to 10 or 20 times the rate of respiration. If in the phytoplankton of the Central Pacific photosynthesis is only 10 times the respiration or less, variations in the respiration of the unicellular forms with which we most likely are working might be sufficient to reduce the photosynthesis as observed.

SUMMARY

A variation between photosynthesizing ability of phytoplankton collected at sea at

0800 and 1900 hours was found when utilizing the carbon¹⁴ light-dark bottle technique. This led to the hypothesis that there is a daily periodicity in the photosynthesizing ability of organisms. Preliminary tests indicate this hypothesis to be valid and thus a theory to be tested further. The variations to be expected include a rather rapid drop in photosynthesizing ability near sundown and a gradual increase thereafter to a maximum during daytime. It is as yet unknown whether there are concordant variations in oxygen consumption or chlorophyll content.

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NOTES AND COMMENT

A rapid live-sexing technique for *Urosalpinx cinerea* and *Eupleura caudata*, with notes on previous methods¹

Very little is known concerning sexuality in muricids. Previously published methods for sex determination involve denuding the snail by cracking its shell in order that the penis or color of the gonad might be observed. The advantages of live-sexing over sacrifice-sexing are apparent.

Early in the present study it was noted that individuals of both species would attach to any suitable substratum on or over which they were held for a short time. Following the snail's attachment it proved possible, by careful manipulation, to rotate the shell until the area of the head just postero-ventral to the base of the right tentacle was exposed. Sex could then be determined by the presence or absence of a penis. The oblique, external ridge caused by the vas deferens could also be seen in oblique light and used as supporting evidence.

A stereoscope on an adjustable extension arm stand, a universal microscope illuminator positioned so that a beam of light could be directed onto the subject, a tray of salt water warmed to room temperature, and an arm rest for steadiness constitute the equipment employed.

The technique involves the following steps: drills to be sexed are rinsed, allowed to adjust to the temperature of the sea water in the examining tray, and left undisturbed for a short period. A drill is then selected and, without being lifted free of the water, transferred to the inside tip of the left index finger where it is held loosely, aperture downward, until it attaches to the

skin with its foot. Optimal alignment seems to be about 45° across the finger. When attached, the snail is carefully rotated with the thumb until the right side of its head is fully exposed.

The light source, preferably with a beam of variable intensity, is used when needed, but it is not turned on until after the snail is exposed, because these animals will not extend as rapidly under strong light. If an individual is uncooperative, it is best to replace it and try another. Usually the most refractory snails, however, can be exposed on a second try. The pressure on the snail should be light and the hands steady. Samples collected from very cold water (2–4°C) may have to warm slowly for several days. Dead drills should be removed from the warming containers to prevent spoilage. It is possible to sex and measure about 50 drills per hour, using vernier calipers to take total shell length. Without measuring, approximately 90 can be sexed in an hour. Undoubtedly greater speeds are possible with practice.

Shortly after this method was developed the paper of Wong and Wagner (1954) came to my attention. Their method of live-sexing the gill-breathing, amphibious snail *Oncomelania nosophora* differs from ours in that the subject is placed in a shallow tray of water with its aperture upwards. A strong light beamed into the aperture evidently stimulates the snail to right itself in an attempt to escape the light. When its foot is extended the penis can be seen. Although this method has not been tried on oyster drills, our technique has the advantage that the subject can be manipulated, without retracting, merely by careful movement of the hand.

With the present method it has been possible to observe other external features of the drills. Some have one, usually the right,

¹ Contributions from the Virginia Fisheries Laboratory, No. 67. This research was conducted by the Virginia Fisheries Laboratory under a contract with the U. S. Fish and Wildlife Service. It was financed with funds made available under provisions of Public Law 466, approved by the 83rd Congress, July 1, 1954 (Saltonstall-Kennedy Act). The assistance of Mr. C. L. MacKenzie is gratefully acknowledged.

or both tentacles amputated at various levels. By the denuding technique one could not be certain that fragmentation of the shell did not cause this. Occasionally multiple eyespots or none in a single tentacle, doubly- or triply-branched tentacles, and other anatomical anomalies have been seen. One *E. caudata* possessed what appeared to be a small second penis immediately posterior to the larger one. Ciliary action of foot and head surfaces may also be observed.

The reliability of this technique was determined in the following manner: (1) pairs of both species exhibiting copulatory behavior were sexed and in 33 out of 34 cases consisted of one male and one female, the other case involving two *Urosalpinx* males; (2) a group of 16 to 18 egg-laying females was sexed precisely according to our criteria; (3) a graded series of 89 males (7.8–23.2 mm shell length) and 111 females (7.2–26.5 mm) were live-sexed, then denuded and visually examined. Their gonads were then smeared in filtered sea water and examined microscopically. All males showed viable sperm; 103 females possessed vitelline spheroids. The presumptive females with no spheroids were mostly small, ranging in size from 7.2 mm to 9.6 mm with undeveloped gonads. A single large female, 18.2 mm, had no spheroids and the gonad was not discernible before smearing. No spermatozoa were seen in the gonads of the eight negative females; therefore, they evidently were not cryptic males. It was discovered that the enlarged egg-forming organs in the right side of the mantle are reliable indicators of femaleness in denuded drills. Evidently these structures have not been utilized for sexing purposes before.

Penes have been seen on *Urosalpinx* individuals as small as 6.4 mm long. The smallest male *Eupleura* successfully sexed was 12.0 mm. This does not seem too surprising, because *Eupleura* probably has a

more elongate shell than *Urosalpinx* of the same age.

In a sample of 1218 individuals the mean length of female York River *Urosalpinx* (16.54 mm) is only slightly greater than that of the males (15.36 mm). There is significant overlap in the length-frequency curves; therefore, length appears to be as poor an indicator of sex in drills as it is in many other animal groups.

Data concerning gonad color in 175 *Urosalpinx* revealed that 6 males and 27 females were in the whitish-to-light-yellow color range and 76 males and 66 females were yellow-to-orange. Previous authors (Cole 1941, and Federighi 1931) have stated that the male gonad is whitish and the female yellow or orange. This color situation was usually reversed in the specimens examined during the course of our study. Because both color ranges overlap, gonad color seems to be an unreliable indicator of sex. It is patently inferior to the present method because the drill must be denuded to expose the gonad.

It appears that the present sexing technique is reliable. It has been tested in the laboratory and found applicable to *Urosalpinx* and *Eupleura* from Chesapeake Bay and the Atlantic Coast of Virginia. It will probably prove useful to field workers, particularly if a suitable magnifying lens is used for drills below 10 mm in length.

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WILLIAM J. HARGIS, JR.
Virginia Fisheries Laboratory
Gloucester Point, Virginia

BOOK REVIEWS

SELLERY, G. C. 1956. **E. A. Birge.** A memoir; with an appraisal of Birge the limnologist: An explorer of lakes, by C. H. Mortimer. Madison: University of Wisconsin Press. vii + 221 pp. \$3.50.

Birge was associated with the University of Wisconsin from 1876 as a young instructor until his death in 1950. From 1891 through 1925 he served first as Dean of the College of Arts and Science with two periods as Acting President of the University and then for seven years as President. Consequently, the account of Birge's activities is almost a history of the University. Much of the first four chapters of the book helps to illuminate the many aspects of Birge's life and his service to Wisconsin, but there are many details recounted by Sellery—names, places, events, etc., thoroughly familiar to him through his long association with Birge and the University—that must make rather tedious reading for one not already intimately acquainted with the history of the University.

Birge himself, however, could not let any book about him be dull for very long, because he was truly a remarkable person with a great impact on his times. Whereas the first four chapters are concerned primarily with the events in Birge's life, the fifth and sixth, by far the best of the seven chapters contributed by Sellery, concern Birge's ideas on liberal education, pure vs. applied science, literature, and religion as expressed in his many lectures, letters, and essays. He is described as an "inveterate lecturer" with a "glutinous memory." There are many direct quotations in these chapters that make fascinating reading, even though Mortimer complains mildly about the "austerity of his academic literary style." One wishes that his complete non-scientific writings might be generally available. Of particular interest is his letter to Mrs. Peckham in Chapter VI, pointing out how there can be revelation in science, music, and other areas of creative activity as well as in religion when one is receptive by virtue of his background and preparation for the revelation.

But as limnologists we are perhaps most interested in Birge's contributions to our field, admirably summarized and evaluated by Mortimer. Science was just one of Birge's many facets, and with the press of administrative duties at the University it tended to be relegated to a disappointingly minor position for almost three decades. It was extremely fortunate, therefore, that Birge was able to have a man like Juday with him at Madison for 40 years, as a result of which the names Birge and Juday are inseparably linked in limnology. In 1950 the Einar Naumann medal was presented to the University by the International Association of Limnology in recognition of

the great limnological contributions of these two men.

Birge and Juday accomplished a prodigious amount of work, carried on throughout the year in southern Wisconsin, but mainly only in summer when the base of operations was shifted to northern Wisconsin with the retirement of Birge from the presidency in 1925. "They were not summer-vacation limnologists; their approach was the opposite of dilettante. They were by no means averse to speculation; but first of all they assiduously collected the facts." The "unique and really valuable core of their work" consists of their "insight into the mechanisms of stratification, interplay of sun and wind, and the quantitative bonds between plankton activities and dissolved gases." Their most valuable single work is undoubtedly the extensive treatise on dissolved gases published in 1911.

Many persons have wished that Birge and Juday had written a book on limnology, summarizing their ideas and the field in general. Mortimer's essay, which can be read with profit even by advanced students in limnology, helps to amend this deficiency particularly in the physical and chemical aspects of limnology, and points out how much the concepts developed by Birge and Juday dominate even our current thinking in certain fundamental areas.

In very few instances has Birge been shown subsequently to be in error. He refused to believe that the extensive temperature seiches discovered by Wedderburn in the Scottish lochs were also operative in smaller lakes, even though his unpublished data for Green Lake demonstrate the existence there of such movements. Mortimer personally regretted the emphasis by Birge and Juday on the differences between limnology and oceanography, which he thought was "unprofitable and retrograde" because "many problems are common to limnology and oceanography." Juday was already dead but Birge was still alive when the Limnological Society of America, founded in large measure through the efforts of Juday, was enlarged to include oceanographers as the present American Society of Limnology and Oceanography, Inc.

Birge died just 15 months short of his 100th birthday. "Although biology was his profession and the study of lakes the specialty to which he made original contributions, his interest, his knowledge, and his understanding were almost coextensive with that of liberal education."

D. G. FREY

*Indiana University
Bloomington*

GESSNER, FRITZ. 1955. *Hydrobotanik. I. Energiehaushalt.* VEB Deutscher Verlag der Wissenschaften, Berlin. 517 pp.

This is the first volume of a planned 3-volume textbook on aquatic botany and at the same time part of a new series of German monographs on biological subjects (*Hochschulbücher für Biologie*, H. Borris and M. Gersch, editors).

The author, professor at the University of Munich and a long time authority in limnology, calls his text an "ecology of aquatic plants based on physiological principles," stressing the fact that aquatic plant societies are, to a higher degree than their terrestrial counterparts, the expression of their physical, chemical, and biotic environment. In Volume I he discusses the properties of physical conditions in the water and their effect on plant growth and distribution. An indication of the coverage can be given by giving some of the chapter headings which include: Light and the distribution of plants in water; The effect of ultraviolet radiation on aquatic vegetation; Temperature as an ecological factor; The effect of hydrostatic pressure; Water movement and its ecological action; Light, temperature and water movement in their common effect upon the freely floating plants.

The author should be congratulated for his attempt to correlate systematically physiological growth-conditions and plant distribution in a manner which has not been applied sufficiently in textbooks on hydrobiology. His critical analysis of physiological laboratory experiments and their application for natural surroundings is excellent. Sometime the discussion of basic biochemical information (e.g. photosynthesis in the section on chromatic adaptation of marine algae) is rather lengthy; moreover, it is adequately treated in textbooks on general plant physiology.

The book, which contains numerous illustrations and an extensive list of references, should make excellent reading for the general hydrobiologist as well as for the botanist. The student will find valuable information on hydrobiological methods. If the author would slightly simplify his style, which demands good command of the German language, more foreign readers would be able to take part in his enlightening discussion.

HANS GEISSBÜHLER

*Department of Botany
University of Wisconsin*

BRUNS, ERICH. 1955. *Handbuch der Wellen der Meere und Ozeane.* VEB Deutscher Verlag der Wissenschaften, Berlin. 255 pp.

In this compact handbook, the author collects and reviews the world literature on waves, examining it critically for precision and utility, and arranging it in systematic fashion. It is primarily a reference volume on this complicated subject for the practical use of ship, port, and shore structure-designers and seafarers.

This handbook contains the theoretical basis necessary for its practical purpose. The numerous measurement techniques and instruments for observation of the wave elements and forces in use throughout the world are carefully described.

An extensive chapter gives formulas for estimation of wave properties in the absence of actual measurements. Methods for the theoretical computation of wave characteristics are given and certain special wave properties are described. To complete the book, the present methods of wave prediction are reviewed.

Of special importance to American readers is the inclusion of the methods reported in the extensive Russian literature on this subject.

OSKAR ESSENWANGER

*Department of Meteorology
University of Wisconsin*

USINGER, ROBERT L., *et al.* 1956. *Aquatic insects of California.* Berkeley and Los Angeles: University of California Press. ix + 508 pp. \$10.00.

Usinger is to be commended for pushing to completion a cooperative undertaking of this magnitude. The book is our best current compilation and organization of the taxonomy of the 13 orders of insects with aquatic representatives. As a compilation alone it would be valuable, but in addition some of the chapters represent distinct and unique contributions to the field. Regrettably all the orders are not treated with equal competence and imagination.

After a lengthy introduction of 67 pages each order of aquatic insects in accepted phylogenetic

sequence is treated by one or two specialists in the group. A total of 16 persons, chiefly from the western United States, have contributed directly to the various chapters.

This book will be of value far beyond the political boundaries of California in that all the known genera of nearctic aquatic insects are treated. Keys are presented to the genera of adults, often with separate keys for males and females, and also to the immature stages including pupae to the extent they are known. The most

recent previous compilation¹ treats only the stages actually occurring in the water, which necessarily eliminates all adults except among the bugs and beetles. (The minor aquatic orders of Orthoptera and Hymenoptera were not treated at all.) The keys are provided with hundreds of figures illustrating morphological details used in the taxonomy of the various orders.

For each order of insects all the species known to occur in California are treated. Except in the case of tipulids and a few smaller families of Diptera for which only a list is given, keys to adults and immature stages of the California species have been organized. Sometimes quite detailed taxonomic descriptions (in the case of the Lepidoptera) or notes on ecology and biology are given in addition.

Each chapter begins with a general statement on the order, often with information on life histories, ecology, bionomics, and evolution, and ends with a list of selected references. In the case of the Hemiptera, Coleoptera, and Diptera each family is treated as a separate unit with separate bibliographies.

As stated in the preface the purpose of this book is "to point out the central role of insects in aquatic situations, to bring to bear on insects the basic concepts and tools of limnology, and to provide keys and illustrations to aid in the identification of aquatic insects." The proper place for much of this material is in the chapters on the individual orders. Yet a number of the chapters are virtually pure taxonomy, with only the briefest mention if at all of the biology and ecology of the insects. Who besides the specialists in these groups would be really competent to present a meaningful summary of these matters for the guidance and information of others? The coordinating editor might have been a little more insistent on conformity to predetermined standards.

The chapters on Coleoptera and Hemiptera are especially outstanding in that there is a wealth of pertinent biological information as well as a competent treatment of the taxonomy. The chapter on Diptera is also excellent, except that it contains less supplementary information than one would desire. Even this restricted treatment, however, runs to more than 100 pages, so that space may have been the deciding factor. The chapter on aquatic Lepidoptera is very good, based on the recent revision by Lange. It contains a preliminary key to six genera of larvae, whereas Pennak listed only two. The chapter on Trichoptera seems well done, although the bibliography lists only material published subsequent to the 1944 paper of Ross. For other parts of the country, therefore, one would need Ross' paper to get into the regional literature at the species level. In the opinion of the reviewer it would have been desirable to include a few of the major

references from Ross in the current treatment. The list of references in the chapter on the Ephemeroptera emphasizes taxonomic studies carried on in the western states and almost completely neglects biological studies and taxonomic studies from other regions. Such a restricted and provincial treatment fortunately has not been applied to the other groups.

The least satisfying portion of the entire book is the introduction. Usinger had a real opportunity here to contribute a scholarly and authoritative summary on the overall importance of insects in aquatic habitats and their relation to the general principles of lake, pond, and stream limnology. Instead, his summary is an unintegrated patchwork of miscellaneous information that gives the impression of having been hastily assembled. He confuses *production* with *productivity*, according to the current definitions of production as a crop and productivity as a rate, and he talks of the age of a body of water, speaking about the succession from oligotrophy to eutrophy in a geologic or absolute sense rather than an ecologic or relative sense. He feels constrained to express temperature in Fahrenheit rather than centigrade, even though two of the pertinent text figures give only centigrade temperatures and the third has been converted from centigrade. The temperature of pure water at maximum density is approximately 4° C, which is equivalent to 39.2° F. The use of the figure 39.2, however, imparts a false precision, since as Strøm has pointed out maximum density occurs at 3.94° C, which is equivalent to 39.09° F.

Quite a number of chamber-of-commerce type statements are made, which do not enhance the value of the essay, such as, "Probably no area of equal extent in the world can claim a greater variety of aquatic habitats than California"; or, "It is doubtful if any place in the world exceeds or even equals California in extent of water management because of its semiarid climate, intensive agriculture, and high standards of living"; or finally, with reference to the control of pest mosquitoes, "This is contributing in no small measure to the high land values, increased enjoyment of recreational areas, and increased efficiency of workers out-of-doors."

Whereas the other chapters in the book were carefully proofread and have only occasional editorial errors, the introduction has a disturbing number. For example, on p. 39 the date of publication of a paper by Needham and Usinger is listed successively as 1955 and 1954, whereas in the bibliography it is 1956. Various papers referred to in the text, especially on p. 39, are not listed in the bibliography. Some of these are unpublished, but even so the title and location of the manuscript should have been given. On p. 43 the "points method" of Swynnerton and Worthington for expressing the food habits of fish is mentioned, but again the reader cannot find where this method was originally described.

¹ Pennak, R. W. 1953. Fresh-water invertebrates of the United States. New York: Ronald Press. ix + 769 pp.

A glossary of technical terms used in the keys is given at the end of the book, followed by an index to the various taxonomic units.

Probably to keep the cost down because of the large number of illustrations, the volume has been printed by offset rather than letterpress process. The quality of the illustrations varies tremendously from one part of the book to another. Those in the chapter on Hemiptera, based largely on originals, are superb. Many others, however, when compared with the publications from which they were borrowed, have suffered a great loss of detail. Even the printing itself is not of uniform

quality throughout, which leaves the reader quite disappointed.

Thus, the "Aquatic insects of California" represents a really valuable compilation which will be extensively used by limnologists, fishery biologists, and entomologists. Some of the chapters are extremely good, representing distinct contributions to their fields, others only moderately so. On the debit side, the introduction is far from being as stimulating and as carefully edited as it might have been, and the presswork is very patchy.

D. G. FREY

Indiana University
Bloomington

Proceedings of the American Society of Limnology and Oceanography, Inc.

Minutes of the 19th Annual Meeting Storrs, Connecticut August 28, 1956

The 19th Annual Meeting of the American Society of Limnology and Oceanography, Inc., was called to order at 11:05 A.M. by President Alfred C. Redfield; 58 members were present. The minutes of the previous meeting were approved as printed.

President Redfield reported that, in accordance with the directive of the 18th Annual Meeting, the Executive Committee had proceeded with the publication of LIMNOLOGY AND OCEANOGRAPHY. Dr. David G. Frey was appointed Editor and Drs. Edmondson, Emery, Fleming, Haskin, Hasler, Hutchinson, Pritchard, Rawson, and Richards were appointed Associate Editors for the first year. Waverly Press, Inc., of Baltimore, Maryland, was selected as the printer and the first three numbers of Volume I have been issued.

President Redfield informed the members that the Society had become incorporated in the State of Wisconsin and that Arthur D. Hasler had been appointed by the Executive Committee as the Resident Agent of the Society. Dr. Hasler and Dr. Bryson were thanked for their help in the incorporation proceedings, and it was moved and passed unanimously that the secretary extend the thanks of the Society to Professor George Young of the University of Wisconsin Law School for his legal advice and assistance. The Articles of Incorporation and the revised By-Laws of the Society are appended.

President Redfield welcomed Dr. B. Kullenberg, Director, Oceanographic Institute, Göteborg, Sweden, to the meeting.

The following appointments, to serve through the indicated year, were announced by the President:

Nominating Committee: G. L. Clarke, D. S. Rawson, and D. G. Frey, 1956

Identification Service: A. H. Banner, 1958

Apparatus & Supplies: R. F. McAllister, 1958

Editor of LIMNOLOGY AND OCEANOGRAPHY: D. G. Frey, 1959.

The President announced that the 20th Annual Meeting of the Society will be held in Stanford, California, in August, 1957. In September, 1957, a special meeting will be held in Woods Hole, Massachusetts, and Dr. John H. Ryther was appointed chairman of this meeting.

The Society expressed a vote of thanks to Dr. J. S. Rankin, our representative on the local committee, for his arrangements for our meeting at Storrs, Connecticut.

The secretary reported that 60 new members have joined the Society, 61 members have resigned, and 95 members have been dropped for non-payment of dues. The membership rolls of the Society include 671 active members subscribing to the journal, 27 associate members, and 9 emeritus members. Fourteen members have moved without advising the secretary of their change of address, and 127 members are in arrears in dues, but have not yet been dropped from the

rolls. We have 79 library subscriptions to LIMNOLOGY AND OCEANOGRAPHY. The response to the journal is thus very encouraging, since we have more subscribing members and more library subscriptions than had been expected for the first year.

The secretary has recorded with regret the deaths of four members of the Society: A. J. Bajkov, R. W. Eschmeyer, R. C. Osburn, and J. E. Potzger.

The treasurer reported a balance in the Society funds of \$5325.49. This balance represents dues payments and subscriptions for all of Volume I of LIMNOLOGY AND OCEANOGRAPHY but expenditures for only the first two numbers. The financial statement for the period September 1, 1955, to August 31, 1956, is appended.

The officers of the Pacific Section of the Society for 1956-1957 were recorded as follows:

President: George L. Pickard

Vice-President: Marston C. Sargent

Secretary-Treasurer: Maurice Rattray, Jr.

Members-at-Large: Gordon H. Tucker, Allyn H. Seymour

The Secretary announced the following results of a member wide mail ballot for the election of officers and associate editors as reported by Tellers James B. Lackey and Dayton E. Carritt:

President: David C. Chandler

Vice-President: Dale F. Leipper

Members-at-Large:

1-year term: John R. Vallentyne

3-year term: Herbert W. Graham

Editorial Board:

1-year term: G. Evelyn Hutchinson

Francis A. Richards

John H. Ryther

2-year term: W. T. Edmondson

Kenneth O. Emery

Harold H. Haskin

3-year term: Arthur D. Hasler

Donald W. Pritchard

Donald S. Rawson

Dr. Robert Pennak reported on the recent International Limnological Congress which he attended in Helsinki, Finland. He had been informed that the International Association of Limnology would welcome an invitation to meet in North America.

It was moved and passed: that the President and Board of Directors be authorized to investigate the feasibility of inviting the International Limnological Congress to meet with the American Society of Limnology and Oceanography, Inc., in North America in 1962, and be further authorized to extend the invitation if it proves feasible.

Reports of the following committees and representatives were presented and accepted:

Editorial Board

Identification Service

American Association for the Advancement of Science
 American Institute of Biological Sciences
 National Research Council-National Academy of Sciences

It was moved and passed that the Board of Directors investigate the privileges, advantages, and extra cost of Society membership in the American Institute of Biological Sciences.

Dr. Wallen of the AAAS described their program of Biological Education, and announced that the Association would welcome requests for information concerning the program.

Dr. Ruth Patrick announced that grants from the Jessup Fund are available for systematic work at the Academy of Natural Sciences in Philadelphia.

Dr. Sidney Galler announced an invitation from the Argentine Navy for oceanographers to participate in the expedition to Antarctica. He also announced that the Office of Naval Research would like to have prepared an International Directory of Hydrobiology, and suggested that the Society should request official representation on the AIBS Hydrobiology Committee.

Mr. Coleman of the Consultants Bureau, New York, described their services in preparing translations of Russian journals. They would be willing to undertake translations of journals in limnology and oceanography, but a large subscription list would be desirable to keep the individual costs as low as possible.

The meeting adjourned at 12:40 PM.

Respectfully submitted,
 BOSTWICK H. KETCHUM
Secretary-Treasurer

Financial Statement

Sept. 1, 1955–Aug. 31, 1956

Receipts

Cash on Hand, Sept. 1, 1955		\$2424.24
Dues	5481.05	
Special Publications & Library Subscriptions	772.25	
Interest	99.74	
Reprint Sales, Issue 1 & 2	450.20	
Issue 3	187.70	6990.94
Total		9415.18

Expenditures

Postage	111.14	
Miscellaneous Printing	228.74	
Stenographic Services	318.64	
Contributions		
AIBS	100.00	
Nat. Resources Council	25.00	
Travel	87.85	
Addressograph Service	95.52	
Incorporation Expense	12.00	
Pacific Section	43.91	
Miscellaneous	8.95	
Bank Charges	9.03	1040.78

Publication of LIMNOLOGY AND OCEANOGRAPHY

Manufacture (Issues 1 & 2)	2230.12	
Reprints (Issues 1 & 2)	381.00	
Address and Mailing	197.25	
Travel	130.39	
Editor's Expenses	71.99	
Miscellaneous	38.16	3048.91
Total Expenditures		4089.69
Balance		5325.49
Cash on Hand, Aug. 31, 1956		
Savings Account	4520.03	
Checking Account	805.46	5325.49

Articles of Incorporation and By-Laws of The American Society of Limnology and Oceanography, Inc.

We, the undersigned natural persons of the age of twenty-one years or more, acting as incorporators of a corporation under the Wisconsin Nonstock Corporation Law (Chapter 181 of the Wisconsin statutes) adopt the following Articles of Incorporation for such corporation:

FIRST: The name of the corporation is American Society of Limnology and Oceanography, Inc.

SECOND: The purpose or purposes for which the corporation is organized are: The promotion of the interests of limnology and oceanography and related sciences and the furtherance of investigations dealing with these subjects and the publication of the results of such investigations.

THIRD: The Corporation shall have three classes of members to be selected according to the provisions set forth in the Corporation By-Laws.

FOURTH: The corporation shall have at least three directors, or such greater number as may be fixed by the by-laws. Directors shall be elected by the members in the manner provided by the by-laws.

FIFTH: The location of the principal office of the corporation shall be in the City of Madison, Wisconsin, and the name and address of its initial registered agent is Arthur D. Hasler, 454 Birge Hall, University of Wisconsin, Madison, Wisconsin.

SIXTH: The number of directors constituting the initial board of directors of the Corporation is eight and the name and address of each such director is:

Alfred C. Redfield, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

Robert C. Ball, Michigan State University, East Lansing, Michigan.

Bostwick H. Ketchum, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

David G. Frey, Indiana University, Bloomington, Indiana.

John L. Hart, Pacific Biological Station, Nanaimo, B. C., Canada.

Howard T. Odum, Duke University, Durham, North Carolina.

John C. Marr, U. S. Fish & Wildlife Service, P. O. Box 271, La Jolla, California.

Maurice Rattray, Oceanographic Laboratories, University of Washington, Seattle, Washington.

SEVENTH: The name and address of each incorporator is:

Reid A. Bryson, 2055 Pontiac Terrace, Madison, Wisconsin.

Arthur D. Hasler, 205 Lathrop Street, Madison, Wisconsin.

State of Wisconsin }
Dane County } ss

REID A. BRYSON
ARTHUR D. HASLER

Personally came before me, this 26th day of April, 1956, the above named Reid A. Bryson and Arthur D. Hasler, to me known to be the persons who executed the foregoing instrument and acknowledged the same.

/s/ Bettie V. Bigley

Notary Public

Dane County, Wisconsin

My commission expires 6/21/59

BY-LAWS

Section. I. MEMBERSHIP

Membership in this Society shall consist of persons who are actively interested in any aspect of limnology and oceanography. Names of candidates for membership shall be proposed by two members, transmitted to the Secretary-Treasurer, and presented for election either by the Society at the succeeding annual meeting or by the officers of the Society at any time.

Section II. OFFICERS

The officers of this Society shall consist of a President, Vice-President, and a Secretary-Treasurer.

The President and Vice-President shall hold office for one year, and shall be ineligible for re-election for two years after the expiration of their term of office. The Secretary-Treasurer shall hold office for a term of three years and shall be eligible for re-election.

The duties of these officers shall be such as usually pertain to the offices held in similar organizations, and any other duties prescribed by the By-Laws, or assigned by the Board of Directors.

Section III. BOARD OF DIRECTORS

The Board of Directors shall consist of the officers of the Society, the retiring president, the president and secretary of the Pacific Section, and three members-at-large. Any retiring secretary-treasurer shall continue to be a member of the Board of Directors for one year after the conclusion of his term of office.

The term of office of the members-at-large shall be three years, so arranged that one shall be elected each year.

It shall be the duty of the Board of Directors to manage the affairs of the Society. The Board of Directors shall appoint annually a member of the Society who is a legal resident of the State of Wisconsin to act as the agent of the Society. The agent shall be eligible for reappointment.

Section IV. ELECTION OF OFFICERS AND ASSOCIATE EDITORS

A Nominating Committee, to be appointed each year by the President, shall make two or more nominations for President, Vice-President, Secretary-Treasurer (when one is to be elected), and Member-at-Large, and three or more nominations for Associate Editors. These nominations shall be forwarded to the Secretary-Treasurer who shall distribute to all members of the Society ballots bearing names of nominees and blank spaces for writing in personal choices of voting members.

The marked ballots shall be returned to the Secretary-Treasurer, who will place them in the care of two tellers, to be appointed by the President. The tellers shall count the ballots and report to the Secretary-Treasurer, who shall announce the results at the annual meeting. Nominees receiving a plurality of votes shall be declared elected at the annual meeting.

The newly elected officers shall assume office as soon as practicable after the annual meeting.

Section V. ANNUAL MEETING

There shall be one regular annual meeting. This annual meeting shall include at least one business meeting for the Society as a whole, and it shall also provide

opportunities for a program of papers and other features of limnological and oceanographic interest.

The time and place of the annual meeting of the Society shall be determined by the Board of Directors. The Secretary-Treasurer shall give adequate notice of the annual meeting to all members.

Special meetings may also be called and arranged for by the Board of Directors. Notices of any such special meetings shall be mailed to all members of the Society at least five weeks before the date set for the meeting.

Section VI. PUBLICATIONS

The publications of the Society shall be LIMNOLOGY AND OCEANOGRAPHY and such other special publications as may be deemed necessary by the Board of Directors. The Editor of LIMNOLOGY AND OCEANOGRAPHY shall be appointed for a three-year term by the Board of Directors, and shall be eligible for reappointment. He shall be assisted by an Editorial Board of nine or more associate editors, elected by the members of the Society as provided in Section IV. The Associate editors shall be elected for overlapping terms of three years, three editors being elected each year, and they shall be eligible for re-election. The Secretary-Treasurer of the Society shall function as business and circulation manager.

Section VII. QUORUM

At regular business meetings of the Society the members present shall constitute a quorum of the Society, and three a quorum of the Board of Directors.

Section VIII. DUES

a. Active Members: The annual dues for an active member of the Society shall be seven dollars and fifty cents (\$7.50), five dollars (\$5.00) of which shall be designated for the annual subscription to LIMNOLOGY AND OCEANOGRAPHY.

b. Associate Members: Students and a second member of a single family may become associate members whose annual dues shall be one dollar (\$1.00).

c. Emeritus Members: Emeritus Members shall be exempt from the payment of the above dues. Emeritus members must be 65 years of age or older and must have been members of the Society for 20 years, or have been members continuously since January 1, 1940. Application for emeritus membership may be sent to the Secretary-Treasurer by a member who has filled the above requirements.

Associate members and emeritus members are entitled to all of the privileges of full membership, but do not receive LIMNOLOGY AND OCEANOGRAPHY. Emeritus members may subscribe in advance to LIMNOLOGY AND OCEANOGRAPHY at five dollars (\$5.00) per volume.

Dues must be paid in full before current issues of LIMNOLOGY AND OCEANOGRAPHY will be mailed to members. Any member who fails to pay his dues for one year, after two notices from the Secretary-Treasurer, shall be dropped from the membership roll. Any member who has been dropped for non-payment of dues must apply for reelection to membership as provided in Section I. He may obtain missed issues of LIMNOLOGY AND OCEANOGRAPHY, if available, for ten dollars (\$10.00) per volume.

Section IX. AUDITING COMMITTEE

The President shall annually appoint an Auditing Committee of two, who shall audit and report upon the financial record and statement of the Secretary-

Treasurer at the meeting for which it is appointed. The fiscal year shall be the calendar year, and the financial accounts shall be balanced to the last day of December.

Section X. PACIFIC SECTION

The Pacific Section of the Society shall include those members residing west of the Rocky Mountains, and others who wish to be so recorded. The Pacific Section shall arrange its own regional meetings, and shall elect its own regional president, secretary, and executive committee, but dues shall be handled by the Secretary-Treasurer of the parent Society.

The secretary of the Pacific Section shall be reimbursed for expenses incurred but not in excess of one dollar (\$1.00) of the dues collected from each member recorded in the Pacific Section.

Section XI. COMMITTEES

By a system of rotation to provide for continuity of service, the President of the Society shall appoint three or more members, each to serve three years and eligible for re-appointment, to such standing committees as shall be designated by the Board of Directors.

The Chairman of each Committee shall be appointed annually by the President and shall be eligible for re-appointment. Other committees shall be appointed by the President, with the approval of the Board of Directors.

Section XII. AMENDMENTS

These By-Laws may be amended by a two-thirds majority of those voting, either at the regular annual meeting of the Society, or in a mail ballot, provided that, in either case, notice of the proposed action shall have been sent to each member of the Society at least thirty days before the date of the vote.